Historical Relationship of the Honeybee (*Apis Mellifera*) and its Forage; and the Current State of Beekeeping within South Africa

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ABSTRACT

Apis mellifera, the honeybee, is regarded as the most crucial insect pollinator to South African agriculture as it is the only managed pollinator used in the pollination of commercial agricultural crops. Essential to sustaining managed honeybees is the supply of adequate and sustainable forage resources upon which managed honeybee colonies can forage throughout the year. In most instances agricultural pollination services are only required for a brief period of the year, and consequently managed honeybee colonies need to be sustained on a variety of alternate forage resources for the remaining months of the year. As an essential resource in maintaining managed honeybee colonies, honeybee forage can subsequently be linked to the maintenance of agricultural crop pollination. Exotic honeybee forage species have always been an important part of managed honeybee foraging patterns, however recent pressure to control exotic plant species in South Africa has put this type of honeybee forage under threat. This studies' first aim was focused on identifying the historic honeybee forage use pattern in South Africa, thereby identifying which forage species have maintained managed beekeeping up until this point. A comprehensive literature review of the South African Bee Journal, dating back to the journals first publication in the 1910's documented both the exotic and indigenous forage species that have sustained the beekeeper industry in the past. Significance ratings of individual species were determined according to the number of times a species was cited in the literature throughout the review period. Although indigenous species where cited in the literature, the predominately used forage species was found to be exotic, highlighting the role these species played in the development of South African beekeeping. Secondly, this study identifies and highlights the current honeybee forage usage pattern in South Africa. By means of a country wide honeybee forage questionnaire, honeybee forage usage patterns were determined based on forage species usage by beekeepers in different provincial regions. Important forage species were highlighted in each region on the basis of number of colonies using individual forage species. In addition to identifying current forage usage, this questionnaire was able to help estimate the number of managed honeybee colonies in South Africa at present, given that census data is not yet available. Even though there is currently a greater awareness and usage of indigenous forage species, it remains that the predominantly used forage source are exotic forage species. Whilst there appears to be a movement and awareness towards the use of indigenous forage species across South Africa, forage species usage patterns have not shift dramatically in the last century. In order to fulfill their foraging requirements, managed honeybee colonies remain heavily dependent on exotic species, especially that of Eucalyptus and certain agricultural crop species. The removal of Eucalyptus should thus just

be done in sensitive environments, while all woodlots should be demarcated and managed to ensure continued forage availability. In turn growers of forage crops should be made aware of their contribution to provincial honeybee forage resources.

OPSOMMING

Apis mellifera, die heuningby, word beskou as die belangrikste insek bestuiwer vir kommersiële boerdery in Suid Afrika, aangesien dit die enigste bestuurde bestuiwer is wat vir kommersiële landbou-gewasse gebruik word. Die beskikbaarheid van voldoende en volhoubare voedselbronne vir bestuurde heuningby kolonies is noodsaaklik vir hul voortbestaan. Bestuiwing deur hierdie insekte is in die meeste gevalle net nodig vir 'n kort tydperk elke jaar, dus benodig bestuurde heuningby kolonies 'n verskeidenheid van alternatiewe voedselbronne vir die oorblywende maande. Heuningby voedselbronne is noodsaaklik vir die handhawing van heuningby kolonies, en dus kan die beskikbaarheid van hierdie bronne gekoppel word aan die onderhouding van landbougewas bestuiwing. Uitheemse heuningby voedsel spesies is belangrik vir die voortbestaan van die heuningby, maar 'n toename in uitheemse plant spesies bestuur bedreig hierdie heuningby voedselbronne. Die eerste doel van hierdie studie was om die historiese heuningby voer gebruik patrone in Suid Afrika te identifiseer, om vas te stel watter plant spesies tot nou toe belangrik was vir byboerdery. 'n Omvattende literatuuroorsig van die South African Bee Journal, vanaf die eerste publikasie in die 1910's, het bevestig watter inheemse en uitheemse spesies belangrik was vir die voortbestaan van byboerdery in die verlede. Betekenis gradering van individuele spesies was bepaal volgens die aantal kere wat 'n spesies aangehaal is in die literatuur binne die oorsigtydperk. Alhoewel inheemse plant spesies aangehaal was in die literatuur, was die meerderheid van die spesies uitheems. Dit dui dus die belangrikheid van uitheemse spesies aan vir die ontwikkeling en voortbestaan van Suid Afrikaanse byboerdery. Die tweede doel van hierdie studie was om die huidige kos soek patrone van die heuningby in Suid Afrika aan te wys. Die heuningby voer gebruik patrone is bepaal deur 'n landwye vraelys, wat die voedselbron spesies van byeboere in die verskillende provinsies ondersoek het. Belangrike voedselbron spesies in elke streek was uitgelig in terme van die aantal by kolonies wat daardie spesie gebruik. Hierdie vraelys was ook gebruik om vas te stel hoeveel bestuurde heuningby kolonies daar tans in Suid Afrika is, aangesien sensus data nog nie beskikbaar is nie. Alhoewel daar tans 'n groter bewustheid is van die gebruik van inheemse spesies as 'n voedselbron, word uitheemse spesies steeds die meeste gebruik. In die laaste eeu was daar nie 'n dramatiese verskuiwing vanaf uitheemse na inheemse spesies nie, ten spyte van die toeneemde bewustheid. Ten einde hul voedsel vereistes te voldoen, bly bestuurde heuningby kolonies afhanklik van uitheemse spesies, veral Eucalyptus spesies en sekere landbou-gewasse. Eucalyptus moet net in sensitiewe omgewings verwyder word, en bebosde gebiede moet afgebaken en bestuur word om te verseker dat hul as volhoubare voedselbronne beskikbaar bly. Verder moet produsente van

gewasse wat byeboere kan gebruik bewus gemaak word van hul bydrae tot die voedselbronne van bestuurde heuningbye in hul streek.

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Chapter One

GENERAL INTRODUCTION

1.1. Global Importance of Insect Pollination

Pollination is one of the essential parts of life, as it is the process by which pollen is transferred during the reproduction of plants and in doing so enabling fertilization and sexual reproduction (Jarvis *et al.*, 2007; Kevan, 1999; Kevan & Viana, 2003). Pollination allows for the continuation of plant life and the subsequent survival of all other plant-dependant life. Pollination can be accomplished via either self-pollination or cross pollination (Hoopingarner & Waller, 2010), which is the transfer of pollen from one plant to another (Hoopingarner & Waller, 2010) and is reliant on a form of pollinator for pollen transfer.

The most common global pollinators are insects (Klein *et al.*, 2007; Richards, 2001), which transfer pollen between flowers as a result of their activity when visiting plants for feeding, breeding or shelter. In order for effective pollination to take place a pollinator must visit a flower in such a way and within a certain time period that viable pollen is transferred from anther to stigma (Kevan, 1999). Although the bulk of Global food demands associated with the human diet (ca. 65%) relies on agricultural yield independent of animal pollination, a sizeable percentage (ca. 35%), consisting of many of the fruits and vegetables making-up a healthy human diet, is nonetheless dependent on a form of pollinator enabled pollination (Klein *et al.*, 2007; Richards, 2001). Not only are pollinators essential to agriculture, but pollinators are responsible for maintaining ecological systems and global biodiversity (McGregor, 1976; Rebelo, 1987; Kevan & Viana, 2003).

Solitary bees, bumblebees and honeybees are the most important insect pollinators for the pollination of self-infertile agricultural crops (Free, 1970; Kevan & Viana, 2003). These insects are a critically important input in the production of a multitude of agricultural crops (Gallai *et al.*, 2009). Aside from the previously mentioned pollinators, wasps and ants (*Hymenoptera*), as well as flies (*Diptera*), moths and butterflies (*Lepidoptera*) and some families of beetles (*Coleoptera*) visit flowers (Kevan, 1999; Nicolson, 1998) and therefore can provide a pollination service. Although the total value of insect pollination globally has not been estimated (Kevan, 1999), studies have valued the insect pollination service to agriculture at approximately €153 billion per annum (Gallai *et al.*, 2009).

Wild pollinator communities play an essential role in providing pollination services to both natural and agriculture systems (Wilson, 1987; Kevan & Viana, 2003). Crop pollination by wild insects is considered an important ecosystem service (Palmer *et al.*, 2004; Kremen *et al.*, 2002; Losey & Vaughan, 2006; Boyd & Banzhaf, 2007; Allsopp *et al.*, 2008). Where agricultural practises have grown into large-scale commercial enterprises, however, the ability of wild pollinator communities to fulfill the required level of agricultural pollination diminishes, and their contribution can become insufficient (Kremen *et al.*, 2002; Aizen & Harder, 2009). Consequently, agriculturalists have looked towards managed pollinators to supplement the necessary pollination service required (Kremen *et al.*, 2007; Steffan-Dewenter & Westphal, 2008). The most commonly used managed pollinator is the honeybee, *Apis mellifera*, which is considered the most economically valuable pollinator of crop monocultures worldwide (McGregor, 1976; Tepedino, 1980; Kevan, 1999; Klein *et al.*, 2007; van Engelsdorp & Meixner, 2010).

1.2. Global Honeybee Declines: Potential Linked Risks

Concerns of ensuring continued pollinator interactions have recently arisen as a result of reported global declines in insect pollinator abundance (Biesmeijer *et al.*, 2006; Klein *et al.*, 2007; Gallai *et al.*, 2009). Such declines have led to an increased awareness and policy action in order to secure sustained pollination for both ecological and agricultural systems (Aizen *et al.*, 2009; Potts *et al.*, 2010). Organizations such as the Food and Agriculture Organization (FAO) and the International Pollinator Initiative (IPI) have become increasingly more involved in research into the protection of global pollinators (Kevin & Philips, 2001), and have subsequently begun the “Global Pollinator Project” (International Pollinator Initiative, http://www.internationalpollinatorsinitiative.org/jsp/globalpollproject.jsp) in a bid to identify and conserve pollinator interactions worldwide, as it is believed that an understanding of pollination ecology will lead to a better agricultural economy through better and more sustainable yields (Jarvis *et al.*, 2007).

The honeybee is the key pollinating agent for approximately 52 of the leading 115 global food commodities (Klein *et al.*, 2007). Honeybees are therefore undoubtedly the most important managed pollinator (Morse, 1991). Recently drastic declines of managed honeybee populations have been recorded (Meffe, 1998; Potts *et al.*, 2010) and consequently concerns regarding the sustained pollination of agricultural food crops persist worldwide (Allen-Wardell *et al.*, 1998; Olroyd, 2007; Neumann & Carreck, 2010).

Honeybees, are susceptible to a variety of diseases and environmental threats (Genersch, 2010), many of which have increased in the last decade possibly explaining recorded declines. Increasing evidence indicates that the intensification of agriculture in recent decades, alongside changes in land use and farming practices, has impoverished farmland as a habitat for insect pollinators (Carreck & Williams, 2002; Naug, 2009). This, coupled with the potential dangers of pesticides, specifically insecticides, and honeybee pests and diseases such as the parasitic mite *Varroa* destructor and the bacterial disease American foulbrood (caused by the gram-positive bacterium *Paenibacillus* larvae) (McGregor, 1976; Ashiralieva & Genersch, 2006; Jarvis *et al.*, 2007; Stankus, 2008) are taking their toll on global honeybee populations. In some areas of the world, “Colony Collapse Disorder” (CCD), which refers to an unidentified influence or series of influences that are causing sudden honeybee population declines (Genersch, 2010) has increasingly also been considered as a main cause of honeybee colony losses. CCD is described by Oldroyd (2007) as a mysterious syndrome in which for no apparent reason, honeybee colonies will abscond from a hive leaving behind no dead bees but often nectar and pollen reserves in addition to brood. CCD has already had a serious impact on honeybee colony numbers in the United States of America as well as parts of Europe (vanEngelsdorp, & Meixner, 2010). The decline in natural landscapes, and more specifically, honeybee forage, is also beginning to surface as a major influence in honeybee problems (Potts *et al.*, 2005; Klein *et al.*, 2007).

1.3. Importance of Forage Resources to Maintain Honeybees

Honeybee forage directly affects the health and security of honeybee populations (Bohan *et al.*, 2005) as the availability of adequate honeybee forage has impacts on both beekeeping profitability and bee health (vanEngelsdorp & Meixner, 2010). Examples of how changes in agricultural practice has effected honeybee forage loss is seen in the increased use of fertilizers which has led to the reduction in the rotation of legumes, a well-used honeybee forage resources in cropping systems. In addition the extensive use of herbicides as a weed control measure reduces this weed resource utilized by honeybees, both within crops and at crop edges (Bohan *et al.*, 2005).

An additional factor associated with modern agriculture, which has been found to affect the health of honeybee populations is the use of monoculture crops as a source of honeybee forage (Brodschneider & Crailsheim, 2010). Characteristically honeybees gather diverse mixtures of pollens from a variety of plant species, which allows for a balanced and diverse diet (Dimou & Thrasyvoulou, 2009; Nicolson, 2011; de Lange *et al.*, 2013). Pollen is the only source of proteins and amino acids in the honeybee diet and thus crucial for their survival and development (Schmidt *et al.*, 1995); however, colonies used for pollination in agricultural areas are often forced to feed on monocultures and face a less diversified diet of pollens which potentially does not provide all the essential amino acids and trace elements required for optimum growth and survival (Schmidt *et al.*, 1995). This nutritional stress, among other factors, may be responsible for high colony mortalities (Naug, 2009) as nutritional stress can lead to a weaker immune system which potentially leaves honeybee's susceptible to diseases or pollution (Alaux *et al.* 2010). So, although there are often large quantities of forage available, the lack of forage diversity can lead to a shortage of crucial elements, and can diminish honeybee's ability to resist diseases leading to colony mortalities (Chauzat *et al.*, 2009).

vanEngelsdorp and Meixner (2010) postulate that both changing agricultural practices as well as increased urbanization have decreased the availability of suitable honeybee apiary sites. These landscape changes reduce forage obtainability inducing knock-on effects on honeybee health. Lack of suitable honeybee forage can lead to honeybee colony malnutrition, which subsequently can become more susceptible to disease outbreaks (Gilliam, 1986) and are more vulnerable to pesticide exposure. Global environmental degradation is generally adding stress to honeybee colonies to find suitable forage resources (Oldroyd, 2007), ultimately leading to their declining numbers.

Accordingly, in order to maintain honeybee populations it is important to ensure the conservation and management of sufficient forage resources within agricultural and surrounding natural landscapes (Zhang *et al.*, 2007); these resources including both suitable nesting habitat and sufficient floral resources (i.e. nectar and pollen; Kremen *et al.*, 2007). Honeybees sample a wide variety of forage species; however, they tend to exploit only the highly profitable ones (Hepburn & Guillarmod, 1991). Therefore, it is necessary not only to secure the diversity of forage species used by honeybees but also to add emphasis on the conservation of the most important species.

1.4. South African Honeybee Forage Scenario

South Africa is strongly reliant on insect pollinators to pollinate a wide range of agricultural crops. The two indigenous honeybee subspecies, *Apis mellifera scutellata* (African honeybee) and *A. m. capensis* (Cape honeybee) are considered as the most important and dominant agricultural pollinator species in South Africa (Hepburn & Radloff, 1998; du Preez, 2010). The two subspecies are separated regionally from one another by occurring on either side of a naturally maintained hybrid belt (du Preez, 2010). The distribution of *A. m. capensis* more or less coincides with the distribution of the fynbos biome and the winter rainfall area of South Africa (Hepburn & Guillarmod, 1991), while *A. m. scutellata* is found north of the hybrid belt outside of the major winter rainfall areas (Hepburn & Radloff, 1998). The subspecies differ from one another in their biogeographical origins (Hepburn & Radloff, 2002), morphometric characteristics (Hepburn & Radloff, 1998) and in their behavioural and morphological traits (Beekman *et al.*, 2008).

Regardless of the subspecies, South African honeybees are vital for commercial crop production as both subspecies are extensively managed by South African beekeepers and rented for pollination. For example, managed Cape honeybees are used to pollinate at least 26 crops in the Western Cape, most notably in the deciduous fruit industry (Allsopp & Cherry, 2004). This industry earns in excess of R7 billion per annum and produces in excess of three million metric tons of deciduous fruit (HortGro, 2012), most of which is dependent on the pollination service provided by managed Cape honeybee colonies. There is thus a demand for and reliance on managed pollination in South African agriculture.

Although South African honeybee populations are not currently demonstrating the same declines as honeybee populations in other parts of the world (Neumann & Carreck, 2010; Strauss *et al.*, 2013), they are subject to the same threats and do need to be sustained and protected if they are to continue providing the essential pollination service demanded by commercial South African agriculture (Allsopp *et al.*, 2008; Dietemann *et al.*, 2009). Honeybee pests and diseases, including the parasitic mite *Varroa* destructor and the bacterial disease American foulbrood, do exist in South Africa, but as yet drastic declines in populations have not been seen. However, as with other global trends, a real threat facing South African honeybee populations, and which is already having an impact on the honeybee industry (Allsopp & Cherry, 2004), is the decline of suitable and reliable honeybee forage. South African beekeepers have traditionally relied on a diversity of honeybee forage species for the upkeep of their colonies, swarm capture and honey crop for decades (Johannsmeier, 2001). Strong relationships between the beekeeping industry and forage species relied upon have developed throughout the country. Without the diversity of honeybee forage species the South African beekeeping industry would not be able to sustain the large numbers of honeybee colonies needed for agricultural pollination. Some of these honeybee forage relationships are discussed below.

1.4.1. Beekeeper-Forage Relationship in South Africa

South Africa does not have many strong and reliable indigenous forage species as many of the species used are often variable and unreliable forage resources (Johannsmeier, 2001). Indigenous forage species such as Protea (*Proteaceae*), Keurboom (*Virgilia capensis*) and Cape Chestnut (*Calodendrum capense*) may all produce nectar and pollen suitable for honeybees but generally not to the same degree as exotic forage species, such as *Eucalyptus* species (Davidson 1970).

The sugar gum (*Eucalyptus cladocalyx*), for example, is stated by Johannsmeier (2001) to be the single most important honeybee forage plant in South Africa, over and above any of the other approximately 149 species of *Eucalyptus* planted in South Africa, which alone is a formidable forage source (Forsyth *et al.*, 2004; May, 1969). *Eucalyptus* species were first introduced into South Africa originally as a timber source (Loock, 1949) and have consequently become the most significant managed honeybee forage source. However, in recent years pressure to control exotic invasive plant species from South Africa has been growing considerably and in 1995 the Working for Water Program was launched (Richardson & van Wilgen, 2004). The program was dedicated to conduct and coordinate exotic invasive plant management and removal throughout South Africa, focusing on those species that were most detrimental to water resources (Richardson & van Wilgen, 2004; Hobbs, 2004). Heavily water-dependent exotic species were identified and highlighted for immediate removal. The *Eucalyptus* species in question were listed as environmentally destructive (invasive water users) in the Conservation of Agricultural Resources Act 43, of 1983 (CARA List) (Glazewski, 2005), and thus were up for reduction and control (Allsopp *et al.*, 2008). Seven *Eucalyptus* species are currently listed on the amended CARA list, only one species *Eucalyptus lehmanni* (Spider gum) is categorized as *"most destructive"* and warrants unconditional removal, the other six species may be retained in a non-sensitive ecosystem under permit (Allsopp & Cherry, 2004). Nevertheless, the seven listed *Eucalyptus* species play an important role in providing honeybee forage throughout the year, and the loss of these species would have serious implications for the beekeeping industry. Consequently, conflict arose between the beekeeping industry and environmental agencies responsible for the policy (Allsopp *et al.*, 2008; de Lange *et al.*, 2013).

South African beekeepers argued that the policy regarding *Eucalyptus* removal was biased in favour of the environmental benefits gained from such removal, and did not take into account the disadvantage which the beekeeping industry would incur from the loss of forage (i.e. see de Lange *et al.*, 2013). Furthermore that forage resources loss and the consequent reduction in honeybee populations, as well as the ability to provide pollination service to commercial agriculture, was not factored into the policy. In response to this threat extensive deliberation and negotiation took place between Working for Water, the South African Bee Industry Organization (SABIO) and the Agricultural Research Council (ARC).These deliberations eventually lead to an amended CARA list whereby *Eucalyptus* species that where categorized in the original CARA list where re-classified, and in most circumstances, *Eucalyptus* trees existing outside of riparian zones, mountain catchment areas or areas of high environmental concern no longer required specific designation for removal. This amendment is seen to be an improvement on the original CARA version as these recommendations should be less detrimental to the supply and maintenance of honeybee forage. Unfortunately these new updated regulations are still to be promulgated.

Excluding *Eucalyptus* and agricultural crop species, there are approximately 250 exotic tree species in South Africa, of these 126 have been recognized as sources of nectar and pollen for honeybees (Johannsmeier, 2007). Although it is primarily *Eucalyptus* and crop species that provide the majority of honeybee forage, the role these exotic tree species play in providing forage cannot be ruled out as they often fill the gaps between the major *Eucalyptus* or crop nectar and pollen flows. For example, Johannsmeier (2007) postulates that without the exotic *Eucalyptus* species in present day South Africa, modern beekeeping would be impossible. This is supported by Gardiner's (2004) findings that commercial pollination, as well as honey production (ca. 50%), would not be possible in South Africa without *Eucalyptus*, as it is essential for off-season colony maintenance and pollination build-up. Consequently *Eucalyptus* has been recognized as an essential part of beekeeping in South Africa for many years. As early as 1982 Cooke published an article in the *South African Bee Journal* expressing concerns about the removal of *Eucalyptus*. Similar concerns were voiced by the Western Province Beekeeper's Association whereby the association approached the Divisional Councils and municipalities with various request to protect exotic forage sources (Cooke, 1982). The *Eucalyptus* was even selected by the Green Heritage Committee of the Forestry Council as "Tree of the Year" in 1978; it was selected for its versatile uses as a timber tree as well as its contribution to the honeybee industry (Anonymous, 1978). The beekeeping literature, therefore stresses the importance of these exotic trees for their use as honeybee forage.

1.4.2. Enhancing South African Honeybee Forage

In order to meet an increasing agricultural demand for commercial pollination services, secure and sustainable forage sources for managed honeybees need to be identified and protected in South Africa. The threat posed by exotic forage control and removal is ongoing and must be addressed in order to ensure a solid forage base.

The ultimate honeybee forage source should be a species that fulfils multiple roles, both as a honeybee forage source and as providing another useful commodity such as timber for example. It is economically unviable for beekeepers to own their own land upon which to grow forage for their managed honeybee colonies, a lesson already learnt by some South African beekeepers (Ransom, 2008). However, as Johannsmeier (2007) argues, in some regions of the world, generally trees are the main source of honeybee forage, and as such, by combining apiculture and forestry both forage and protection for honeybees could be provided (Hill & Webster, 1995; Keasar & Shmida, 2009). Plantation species that are of both commercially viable timber crops as well as provide a sustained and heavy forage source can be described as a “win-win” forage source an essential necessity when building a solid forage base. It has been proposed (pers. comms. Allsopp, 2012) that forestry could provide an enormous forage source in South Africa as there are approximately 1.3 million hectares of commercial forestry of which approximately 40% (525 200ha) is planted with various *Eucalyptus* species (Godsmark, 2010). Unfortunately, the forestry industry is sometimes unwilling to allow beekeepers access to place colonies on forestry property as this is seen as a fire threat to the plantation (pers. coms. Allsopp, 2012). Another drawback, however, is that modern forestry targets *Eucalyptus* species that are often not highly profitable honeybee forage sources or that are not allowed to flower. Additionally, insect pests on *Eucalyptus*, such as the nectar feeding fruit fly, reduce the quality of *Eucalyptus* as forage (du Toit, 1987). The future planting of *Eucalyptus* plantations is thus a vital component for increasing South Africa’s honeybee forage.

1.5. Thesis Objectives

In light of the current honeybee forage uncertainties in South Africa, the Working-for-Water program of the Department of Agriculture, Forestry and Fisheries (now Natural Resource Management Fund, Department of Environment) funded a study to evaluate the honeybee forage scenario in South Africa in an attempt to identify critical forage species in order to protect them and/or find replacements for conflict species. In order to secure honeybee forage, in particular “conflict species”, it is necessary to provide scientific evidence that these species serve an important role in the beekeeping industry. It can then be linked to all associated industries, such as the deciduous fruit industry. This MSc research project aims at achieving some of these objectives by reviewing the historical literature on forage usage and assessing current forage usage amongst South African beekeepers. Without this initial evidence it is impossible to identify and protect the forage species critical to the honeybee industry. This study will help to provide the evidence base which can be used by policy makers and associated organizations to protect and manage forage sources. This project forms part of the Honeybee Forage Project implemented by the South African National Biodiversity Institute (SANBI) and the Agricultural Research Council (ARC), and is aimed at having practical and implemental results.

This study is made up of two chapters: an assessment of past honeybee forage relationship that have existed between beekeepers and forage over the last 90 years (Chapter 2); and the current relationship between beekeepers and forage usage (Chapter 3).

1.5.1. Chapter 2 - South African Honeybee Forage History

Information was gathered from all known literature on beekeeping and honeybee forage in South Africa. The vast majority of this information was to be found in the *South African Bee Journal*, dating back to this journal's earliest publication in early 1910. This information was used in this study to represent the honeybee forage sources that allowed for the build-up and maintenance of the South African honeybee industry over the last ninety years. A comprehensive forage species list was then compiled from this data, and all dominant forage species identified and highlighted. The importance of these species, gauged by the extent of their use, was documented, which ultimately can be used to add value to their status and hence their protection. The relationship between beekeepers and the forage sources they most valued was also identified, as was the ratio of indigenous to exotic forage species used. Such a study of South African honeybee forage history is novel in that dominant forage species been not been identified through investigation of historical usage patterns by beekeepers.

The following questions were addressed in Chapter 2:

- Where were forage species traditionally used located?
- What were these individual forage sources used for?
- Which indigenous or exotic forage species have been dominant forage species over the last century in South Africa?
- How reliant have beekeepers been on exotic forage species in the last century?

The outcomes of Chapter 2 allow for a better understanding of the historic relationship between beekeepers and their forage which provide a quantitative foundation for the forage knowledge base.

1.5.2. Chapter 3 - Current Honeybee Forage Usage Patterns

Questionnaire data was collected via a national beekeeper survey, conducted in order to assess the current relationship between South African beekeepers and honeybee forage usage. The questionnaire asked beekeepers to identify which forage sources they most valued to their business, as different forage sources are used at different periods of a honeybee colony year cycle - e.g. some species are used to gather a honey crop whereas others may for instance be used to build up the colony in preparation for an agricultural crop pollination season. These differing forage sources had not been identified on a national scale in South Africa.

The following questions were addressed in Chapter 3:

- How are managed colonies distributed in South Africa across provinces?
- What are the most significant forage species currently used?
- Where are these forage species located?

1.5.3. Chapter 4 - Future Forage Use Recommendations

This study is the first to provide an accurate review and synthesis of the historic record of honeybee forage usage over almost the last century, and therefore provides historical context on patterns of forage usage and the current reliance of the commercial honeybee industry on certain exotic and indigenous plant species. This then provides the first step in accumulation of the evidence base needed to secure and manage these species for future use as forage sources. Questionnaire data collected from beekeepers (Chapter 3) will identify the dominant current forage species which along with the historic record (Chapter 2), will provide a definite honeybee forage species list. A list in which the dominant forage species from both the past and current relationships are combined to allow insights into the dynamics of honeybee forage usage.

Chapters 2 and 3 are written as stand-alone research papers which results in some degree of repetition between the chapters. Chapter 4, the general discussion, explores the relationship between beekeeper and the forage source usage in the previous two chapters. This chapter includes what influence the past forage usage pattern has had on current forage usage patterns and explores the possible future usage pattern. It highlights the importance of securing the dominant forage species not only for commercial beekeeping but all associated industries. Principal recommendations for ensuring the maintenance of significant forage sources and future research opportunities are discussed.

1.6. References

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Chapter Two

SOUTH AFRICAN MANAGED HONEYBEE FORAGE USAGE: CHANGES OVER THE LAST 90 YEARS

2.1. Introduction

Honeybees and honeybee health has recently become a popular topic due to the perceived drastic declines in colony numbers and the realization that honeybees play an vital role in the global pollination of commercial agricultural crops (Genersch, 2010; vanEngelsdorp & Meixner, 2010) . In order to secure the pollination service honeybees provide to global agriculture, they need to be protected from a variety of diseases and environmental threats to which they are susceptible, some of which have increased dramatically in recent years (Genersch, 2010). Additionally, other factors affecting the health and security of honeybee populations is the availability of adequate honeybee forage (Bohan *et al.,* 2005), as this influences both beekeeping profitability and honeybee health (vanEngelsdorp & Meixner, 2010). The lack of suitable honeybee forage can lead to honeybee colony malnutrition, which subsequently may lead to colonies that are more vulnerable to disease outbreaks (Gilliam, 1986) and are more susceptible to pesticide exposure. Therefore, dependable honeybee forage resources are essential for securing continued honeybee colony strength and ensuing agricultural pollination.

On a global scale the importance of dependable forage resources and the impact of forage decline have been widely researched, and in many countries strategies have been put in place to manage honeybee forage resources in order to secure healthy honeybee colonies (Ayers & Harman, 2010). Comprehensive reviews have been performed to assess the consequences of honeybee colony declines and the factors which threaten honeybee populations, including declines in the quantity and quality of forage (Stankus, 2008; vanEngelsdorp & Meixner, 2010). In South Africa, however, an information repository dealing explicitly with honeybee forage does not exist. Reviews dealing with South African honeybee forage are essentially limited to two publications, namely: “Beekeeping in South Africa” (Johannsmeier, 2001) and “Beeplants of the South-Western Cape” (Johannsmeier, 2005). Neither of these publications, however, specifically deals with honeybee forage at a national scale, nor provides a strategy for honeybee forage management and conservation.

South African beekeepers are known to use a diversity of honeybee forage species as nectar and pollen sources for their managed honeybee colonies, and the importance of these sources depends directly on the extent and density in which they occur and in turn are used (Johannsmeier & Mostert, 2001). Beekeepers rely on both minor and major sources (minor sources are used by beekeepers to maintain the colonies between major forage source flowering periods, whereas major sources are used to for activities such as colony build-up or honey harvesting); the minor sources are important to bridge the short periods between the major nectar and pollen flows (Johannsmeier & Mostert, 2001). Both exotic and indigenous forage species are used heavily; however, the most extensively used forage species across South Africa appears to be *Eucalyptus* (Allsopp & Cherry, 2004), which were introduced into South Africa originally as a timber source (Loock, 1948) and have subsequently become the most significant managed honeybee forage source (Allsopp & Cherry, 2004; de Lange *et al.*, 2013). It is hypothesised that commercial pollination services and honey production in South Africa has only been made possible by the introduction of *Eucalyptus* species, which both maintain colonies and produce more than 50% of the South African honey crop (Johannsmeier & Mostert, 2001; Allsopp & Cherry, 2004). Although *Eucalyptus* species have been extensively used throughout South Africa, there are also a variety of other seasonal sources that are used by South African beekeepers, many of which have never been given adequate appraisal as forage species.

As an essential resource in maintaining managed honeybee colonies, honeybee forage can subsequently be linked to the maintenance of agricultural crop pollination. Managed honeybees are reported to be the main agricultural pollinator (Free, 1993), and consequently the forage that maintains colonies needs to be conserved in order to protect the pollination service provided by honeybees. In South Africa the realistic replacement of managed honeybee pollination services by other means (e.g. non-*Apis* pollinators; mechanical pollination) appears limited (Allsopp *et al.,* 2008), and thus the conservation of managed honeybee colonies and associated resources can be considered as imperative.

With the aim of highlighting as well as framing strategies for the conservation and management of important forage resource in South Africa it is important to clearly understand the historic managed honeybee forage usage patterns, and as such this study addresses two questions. Firstly, we measure what the historic value of all honeybee forage species in South Africa is and how this value has changed through the review time period. To assess this, honeybee forage species are recorded and gauged according to the number of times in which they are cited in the literature. Secondly, as South African forage species consists of both exotic and indigenous species, species status (for example exotic/invasive species) will be taken into consideration along with all related competing interests and factors (i.e. from both beekeeping industry and environmental agencies). The degree to which exotic or invasive forage species have been important in providing forage to the South African honeybee industry is assessed and whether this importance has changed over time.

2.2. Methods

Data to determine the past patterns of managed honeybee forage usage in South Africa was collated through a comprehensive literature review. References for reading and assessment were selected from the *South African Bee Journal* as well as the *Southern African Forestry Handbook* (1994). Online literature searches, whilst using various search engines and key words yielded no literature pertaining to honeybee forage in South Africa. Virtually all the literature assessed was collated from the *South African Bee Journal*, dating as far back as to the 1920's.

2.2.1. The *South African Bee Journal*

The *South African Bee Journal* (SABJ) is a quarterly issued bilingual (English and Afrikaans) journal, which is published by the South African Bee Industry Organization (SABIO). SABIO is the national umbrella body for the apicultural sector in South Africa (http://www.sabio.org.za/).

The purpose of the SABJ is to cover events and research happenings in the industry, as well as covering current affairs. SABIO liaises with all provincial beekeeper associations with regards to ensuring that all information from across South Africa that needs to be published in the journal is done so. The journal is circulated to all current members of SABIO, not all, however, are necessarily practising beekeepers. The journal was first published in 1916, and has been in circulation ever since (SABIO, 2009). This journal is specifically aimed at the South African honeybee industry, including all forage/beeplant honeybee relationships, and thus was chosen as the primary source for the literature review of this study and it was thoroughly searched for appropriate forage articles.

This study's literature review was undertaken to obtain all English and Afrikaans literature relating to honeybee forage used by South African beekeepers for their managed honeybees throughout the period 1920 to 2009. This review covers this particular time period as it includes all nine full decades that exist between the SABJ first publication in 1916 and the start of this study. A literature search was undertaken to search through SABJ published between 1920 and 2009 at the Agricultural Research Council's (ARC) Honeybee Research Unit library, at the ARC's Vredenburg campus in Stellenbosch. This library was the only accessible source of all past published volumes of the SABJ. As digitized and electronic copies of the SABJ are not available, all volumes were manually searched for all articles describing the relationship between honeybees and forage in South Africa. All articles that had a reference towards a honeybee forage source, whether it was focused upon a single source or multiple forage sources, were retrieved from the journals and photocopied in order to remove this information from the library. In order to assess the quantity and/or quality of South African forage species, and the extent of their usage only articles which mentioned honeybee forage sources that were considered by the article to be a "good" or "well used" forage source were recorded. Any reference to a forage plant as a poor forage source or was not considered a favourable forage source was disregarded. A total 172 honeybee forage related articles (Appendix I) were extracted from the SABJ. Most authors cited plants to species level, however, some authors cited only to genus or family level. Where it was possible to distinguish the species name it was added to the entry. If species name were not available, the entry was left at genus level, with '*sp*' indicating that the entry referred to undetermined species.

2.2.2. Electronic Data Entry

Articles relating to honeybee forage were collated and organized into decades starting in 1920 and terminating in 2009, a total of 89 years in nine decades. The honeybee forage related content of each article was carefully recorded into Microsoft Excel spread sheets. From each article the following was recorded: the date of publication (month and year); honeybee forage species and common name; the article-stated South African provincial distribution; article-stated forage bloom period; nectar and pollen source quality; author name; volume and page number. Each forage source mentioned was treated as a single entry/citation, and all previously mentioned information was recorded for each entry/citation regardless of number of entries recorded from a single article. SABJ articles collated differed in their purpose and content. Certain articles were directed at discussing the honeybee forage quality of a single forage source whilst others mentioned multiple species. As a result not every article included the same information; some entries did not have South African provincial/regional distribution data whereas others did. The same applied to the forage bloom period and nectar/pollen value data. Where this data was absent from the article it was left blank in the electronic entry; at no point was this data added from an alternate source. Where a honeybee forage species entry's family names did not exist, the family of forage species was researched and added to the entry. Associated to each entry was the particular species growth form and native status. Non-South African forage species where marked as "Exotic" and indigenous species were marked "Indigenous". Each entry was associated to a growth form, namely: Crop – including all agricultural and garden crop species, all classified as Exotic; *Eucalyptus* – included all *Eucalyptus* species, consisting of two genera, all classified as Exotic species; Shrub and Herbs (referred to as Shrubs from here on) – including creepers, annuals and biennials, bulbous plants, ground covers, succulents, and herbs, where classified as either indigenous or exotic; Tree – all tree species classified as either indigenous or exotic, but excluding *Eucalyptus* species; Weed – all indigenous or exotic honeybee forage species considered to be weeds. These five growth form categories were chosen due to their past use in popular South African honeybee forage literature, such as seen in the 2005 publication “Bee plants of the South-Western Cape” (Johannsmeier, 2005). Grouping forage species into these growth forms has the added advantage of organising forage plant data in categorical order to place value to certain growth forms and forage types.

2.2.3. Data Analysis

Honeybee forage entries were organized into three 29 year time frames (i.e. 1920 to 1949, 1950 to 1979, and 1980 to 2009). The lengths of the time frames were decided upon due to their equal lengths and good representation of three distinctive time periods in the South African honeybee industry. Subsequently the data within each time frame was further ordered into six geographic regions of South Africa, namely: 1. Eastern Cape; 2. Free State/Gauteng/North West; 3. KwaZulu-Natal; 4. Mpumalanga/Limpopo; 5. Northern Cape; 6. Western Cape. The combined provincial regions where discussed and extensively deliberated upon and were agreed to best represent similar geographic regions representative of vegetation, beekeeper behaviour and forage pattern usage (Allsopp and Johannsmeier pers. comm., 2012). Within each provincial/regional area entries/citations were classified according to their indigenous/exotic status and growth form, in order to highlight what species have had an effect in each particular geographic region of South Africa.

Within each of the three 29 year time frames the species list for that particular time period was further manipulated to distinguish important forage plant species. Importance of a forage species was assumed to be reflected by the number of citations of a species for the particular time period in the *South African Bee Journal* articles. Where multiple entries of the same species occurred the entries where condensed into a single entry with a column recording the number of times each species was cited. Additional species data, such as provincial distribution and forage bloom period, were also condensed. Thus species and citation number were collected for all entries and honeybee forage species importance was ranked accordingly. Species were highlighted as significant if they were cited three or more times throughout the literature review period. Where individual species citation number was

≥5% of the total citation for that time frame the species was highlighted as significant forage source and identified into what region it holds that significance. For each of the six provincial regions, a list of the most important species used by beekeepers in each specific province was compiled based on the above criteria.

2.3. Results

2.3.1. *South African Bee Journal*: Numbers of Citations and Forage Articles

The *South African Bee Journal* provided 98.5% of the honeybee forage papers retrieved that dealt with South African honeybee forage aspects. The only other article found to describe honeybee forage plant species, was an article titled "*Beekeeping and Forestry in South Africa*" published in the *Southern African Forestry Handbook* (1994). This article however only cited 26 (1.5% of all citations used in the study) honeybee forage species, majority of which were *Eucalyptus* species. It is important to note that this literature review covered all honeybee forage reference in South Africa, however very little literature pertaining to honeybee forage was found outside the *South African Bee Journal*.

In the first (1920-1949) and third (1920-2009) time periods the highest numbers of species and citations were recorded. The middle (1950-1979) time period only produced less than half the numbers of species and citations than the other two periods. In total 774 honeybee forage species from 119 families used by beekeepers were cited, with a total of 1749 citations relating to these species (Table 2.1).

Table 2.1: Number of honeybee forage related articles, number of species and number of citations from each time frame as extracted from the *South African Bee Journal*.

Time Frames	# Article	# Species	# Citations
1	65	327	596
2	46	120	258
3	61	524	895
All	172	774	1749

2.3.2. Historically Important Forage Plants: Changes over Time

Forage species usage patterns shifted throughout the literature review's time period, each provincial region in each time frame displaying a differing usage pattern; however exotic forage species dominate across all time frames (Figs: 2.1 & 2.2).

Forage species categories in terms of species number indicate the predominance of exotic forage species usage compared to that of indigenous forage species (Fig. 2.1). In all three time frames exotic forage species dominate, with an overall figure of 68% (526 species) of all forage species being exotic and only 32% (248 species) indigenous. This pattern is constant across all three time frames, with time frame one representing the biggest dominance of exotic forage used (73% vs. 27%). This pattern is due to the high number of *Eucalyptus* (31% of species) species (Fig. 2.1). This is exaggerated in time frame two where *Eucalyptus* make up 47% of species used. Time frame three indicates a more evenly distributed forage usage pattern of exotic and indigenous forage species categories. Indigenous shrubs (16% species) and trees (21% species) are equally matched with exotic shrubs (21% species) and trees (11% species). The *Eucalyptus* (15% species) and crop (15% species) categories are equally matched, but are both outweighed by exotic shrubs (21% species). There is a good usage of indigenous shrub (16% species) and tree (16% species).

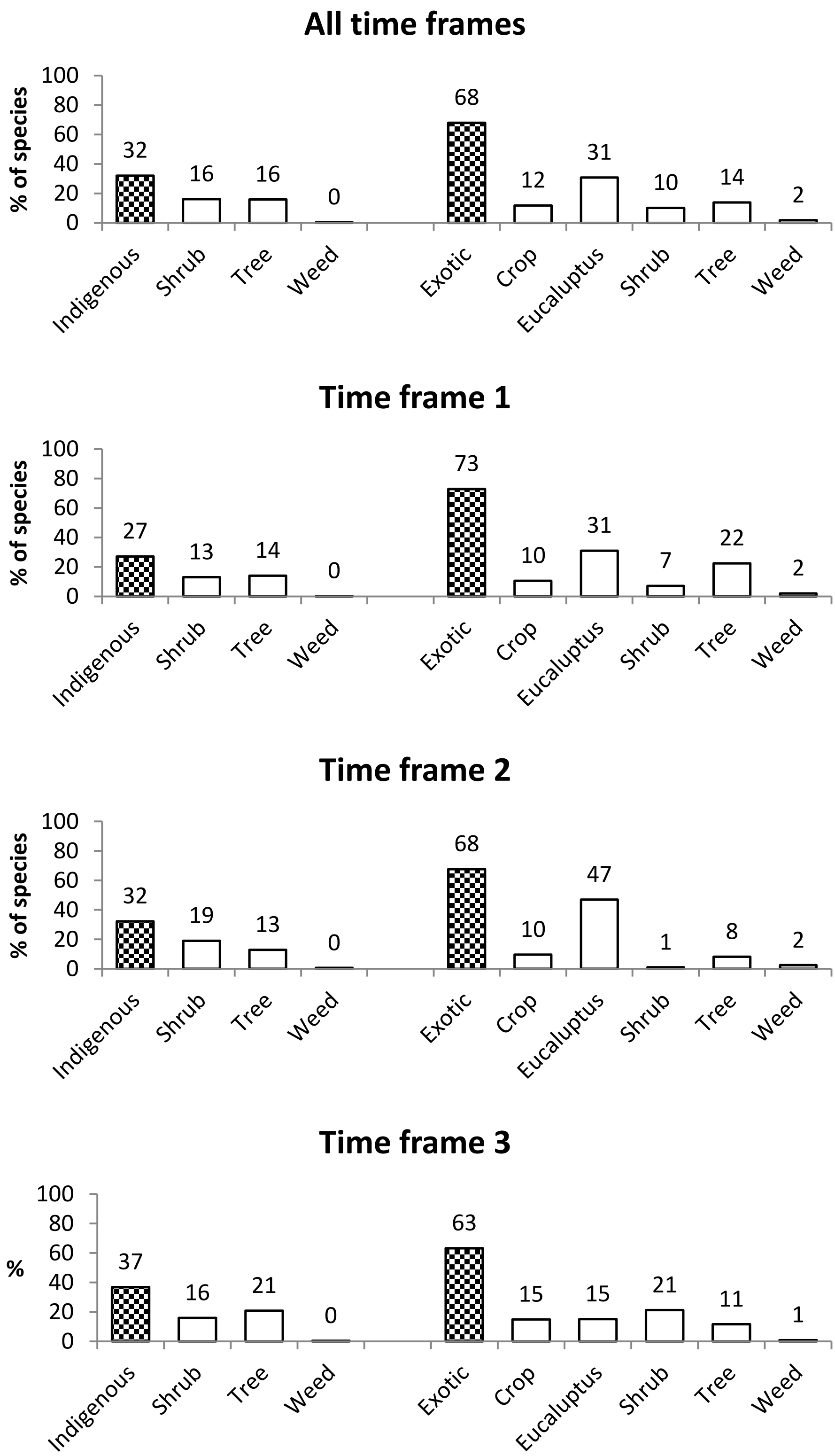

Figure 2.1: Literature review results indicating the number of indigenous and exotic species identified overall and in all three time frames, expressed as a percentage of the total species number. Indigenous and exotic species data expressed out of a total of 100% (categories indicate how total percentage made up).

In terms of the differing levels of citations, 71% of all citations recorded (1242 citations; Table 2.1) represent exotic forage species, and 29% representing indigenous forage species (507 citations; Fig. 2.2). *Eucalyptus* species alone contributed 43% of all citations (Fig. 2.2). *Eucalyptus* citation numbers were high in all three time frames, especially in time frame two where 58% of all citations where indicating *Eucalyptus* species (Fig. 2.2). Exotic crop citations, except for time frame two, remain constant with an overall average of 11% of citations referring to crop species. In addition to *Eucalyptus*, time frame one had a strong presence of exotic tree (17% citations) citations, whereas time frame three had a high number of exotic shrub citations (13% citations).

Overall, indigenous forage species had a similar level of usage in South Africa across the three time frames, with indigenous shrubs and tree covering 15% and 14% of all citations, respectively (Fig. 2.2). There was an overall increase in the citation of indigenous forage species usage: in time frame one 22% of citations were indigenous; in time frame two 29% citations indicated indigenous forage species; and in the third time frame, 35% of all citations were indigenous (Fig. 2.2). Time frame three was boosted by the number of indigenous tree citations, with 23% of citations representing this category (Fig. 2.2). Indigenous forage categories shrubs (15% citations) and trees (14% citations) overall represented more citations than any of the exotic forage categories except that of *Eucalyptus* (43% citations)

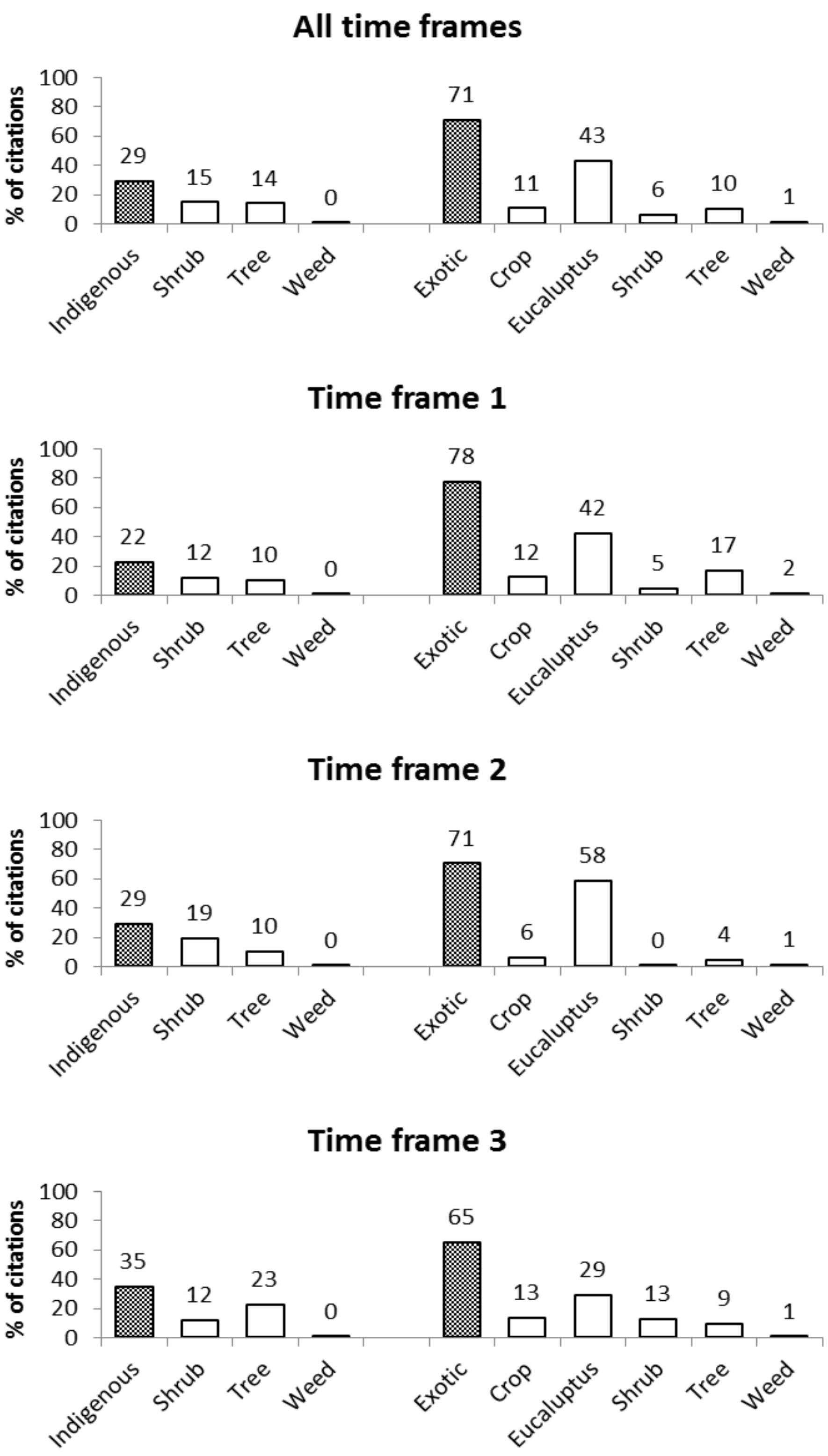

Figure 2.2: Literature review results representing number of indigenous and exotic citations recorded, expressed as a percentage of the total number of citations as well as in all three time frames. Indigenous and exotic data expressed out of a total of 100% (indicate how total percentage made up).

2.3.3. Past Exotic and Indigenous Forage Species Use by South African Beekeepers

Focussing on those 99 species classed as significant forage species (≥ three citations), 62 of these were exotic (19 families) and 37 indigenous (20 families). There were only two exotic families containing ≥5 species, namely Fabaceae (12 species) and Myrtaceae (27 species); and only one indigenous family (Fabaceae with 8 species).

The majority of forage species were only cited once or twice (675 species; 87%). Only six exotic species held a significance ranking (≥5% of the total citation), namely five *Eucalyptus* species and a crop species, *Citrus sp.* which was significant in the first time frame in all regions of South Africa except Mpumalanga/Limpopo and the Northern Cape. The significant *Eucalyptus* species included "*Eucalyptus grandis*" "*Eucalyptus melliodora*" "*Eucalyptus saligna*" "*Eucalyptus sideroxylon*" as well as the genus level *Eucalyptus sp.* held a significant rating in the first time frame.

The only indigenous forage species to hold a ≥5% of the total citation significance rating was *Aloe greatheadii var. davyana* which held this significance in the second time frame in the Free State/Gauteng/North West; Mpumalanga/Limpopo and Northern Cape regions. Of the 62 exotic species listed, 34 (55%) were recorded to have been use by beekeepers in all regions of South Africa, and of the 37 indigenous species 8 (22%) were recorded to have been used throughout the country.

Honeybee forage specie categories represent the forage make-up as grouped into vegetation categories used in Johannsmeier's (2001; 2005) South African honeybee flora publications. The listed exotic species category distribution is, *Eucalyptus* category - containing 27 species (44%), and crops containing 15 species (24%); exotic shrubs contain four species (6%) and exotic trees 11 species (18%), exotic weeds contain five species (8%). The indigenous species were distributed into three categories, indigenous shrubs containing 11 species (30%), indigenous trees containing 25 species (68%) while indigenous weeds contained only one species (2%).

There were two exotic species that did not have cited bloom period data or forage value data and thus were not listed in this study. Only three exotic species (5%) were listed as pollen sources only, and five species (8%) were listed as nectar sources only. Only one indigenous species (3%) was listed exclusively as a pollen source. There was only bloom period and resource data missing from a single listed indigenous specie. All other listed forage species were used as both a nectar and pollen source, however species differ in which resource they best produce.

Table 2.2: Exotic species list, listing all significant exotic forage species. All species listed have been cited ≥3 times throughout the 90 year literature review. Grouped provincial regions include: GP – Gauteng/Free State/North West; MP – Mpumalanga/Limpopo. All bloom periods and forage resource data is as stated in literature sources reviewed. Provincial regions and time frame numbers in bold and shaded in grey indicate forage species that represent ≥5% of total citation number per time frame, and are thus considered the most significant forage sources in that particular provincial region.

EXOTIC SPECIES LIST	Category	Province	Time Frame			Bloom	Resource
ANACARDIACEAE							
Schinus molle	Tree	EC; GP; KZN; MP; NC; WC	1		3	Nov-May	PN
ASTERACEAE							
Bidens pilosa	Weed	GP	1			Feb-Mar	N:P
Helianthus annuus	Crop	EC; GP; KZN; MP; NC; WC	1	2	3	Nov-Apr	N:P(x)
Hypochoeris radicata	Weed	WC			3	Dec-Apr	NP
BIGNONIACEA							
Jacaranda mimosaefolia	Tree	EC; GP; KZN; MP; NC; WC	1		3	Oct-Nov	N
BORAGINACEAE							
Echium plantagineum	Weed	WC			3	Sept-Nov	N:P
BRASSICACEAE							
Raphanus raphanistrum	Weed	WC		2	3	Jun-Aug	PN
COMBRETACEAE							
Combretum sp.	Tree	GP; KZN; MP			3	Sept-Oct	NP
FABACEAE							
Acacia mearnsii	Tree	EC; GP; KZN; MP; WC	1	2		Aug-Nov	P
Bauhinia variegata	Tree	EC; GP; KZN; MP; NC; WC			3	Aug-Sept	NP
Caesalpinia gilliesii	Shrub	EC; GP; KZN; MP; WC	1			Oct-Apr	PN
Cytisus proliferus	Shrub	GP; KZN; MP;	1			-	-
Gleditsia triacanthos	Tree	EC; GP; KZN; MP; NC; WC			3	Sept-Nov	N:P
Medicago sativa	Crop	EC; GP; WC	1		3	Nov-Mar	NP(x)

EXOTIC SPECIES LIST	Category	Province	Time Frame			Bloom	Resource
Melilotus alba	Crop	GP; MP	1			Oct-Feb	NP
Phaseolus coccineus	Crop	GP; MP		2	3	Feb-Mar	NP
Pisum sp.	Crop	GP; WC			3	Jun-Sept	P(x)
Robinia pseudacacia	Tree	EC; GP; KZN; MP; NC; WC	1			Sept-Dec	NP
Tipuana tipu	Tree	EC; GP; KZN; MP; NC; WC			3	Oct-Nov	NP
Trifolium repens	Crop	WC	1			Oct-Nov/Mar-Apr	N:P
LAURACEAE							
Persea americana	Crop	EC; GP; KZN; MP; NC; WC			3	Aug-Sept	NP
MALVACEAE							
Gossypium sp.	Crop	GP; KZN; MP	1			Dec-May	NP
MELIACEAE							
Melia azedarach	Tree	GP; KZN; MP	1			Sept-Oct	N:P(x)
MYRTACEAE							
Corymbia citriodora	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Sept-Oct	NP
Corymbia ficifolia	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Dec-Feb	N:P
Corymbia maculata	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Feb-Apr	N:P
Eucalyptus albens	*Eucalyptus*	EC; GP; MP; WC	1			Dec-Mar	NP
Eucalyptus bridgesiana	*Eucalyptus*	EC; GP; KZN; MP; NC; WC			3	Jan-Feb	N:P
Eucalyptus camaldulensis	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Oct-Jan	NP
Eucalyptus cinerea	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Apr-Oct	N:P
Eucalyptus cladocalyx	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Oct-May	NP
Eucalyptus cornuta	*Eucalyptus*	EC; WC	1			Dec-Feb	NP
Eucalyptus diversicolor	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Feb-Mar	NP
Eucalyptus dunnii	*Eucalyptus*	EC; GP; KZN; MP; NC; WC			3		
Eucalyptus fastigata	*Eucalyptus*	EC; GP; KZN; MP; NC; WC			3	Dec-Jan	NP

EXOTIC SPECIES LIST	Category	Province	Time Frame			Bloom	Resource
Eucalyptus globulus	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Jul-Oct	PN
Eucalyptus gomphocephala	*Eucalyptus*	EC; KZN; WC	1			Mar-Apr	N:P
Eucalyptus grandis	*Eucalyptus*	EC; GP; KZN; MP; NC; WC		2	3	Apr-May	NP
Eucalyptus lehmannii	*Eucalyptus*	EC; WC	1			Sept-Nov	NP
Eucalyptus longifolia	*Eucalyptus*	EC; GP; KZN; MP; WC	1			-	-
Eucalyptus melliodora	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Sept-Nov	N
Eucalyptus paniculata	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Jun-Oct	N
Eucalyptus polyanthemos	*Eucalyptus*	EC; GP; KZN; MP; WC	1	2	3	Aug-Oct	N
Eucalyptus robusta	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Apr-Jun	N:P
Eucalyptus rubida	*Eucalyptus*	GP; KZN; MP		2		Nov-Dec	N:P
Eucalyptus saligna	*Eucalyptus*	EC; GP; KZN; MP; WC	1	2		Dec-Apr	NP
Eucalyptus sideroxylon	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1	2	3	Apr-Sept	N
Eucalyptus sp.	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Jan-Dec	N:P
Eucalyptus tereticornis	*Eucalyptus*	EC; GP; KZN; MP; NC; WC	1		3	Aug-Oct	N:P
Eucalyptus viminalis	*Eucalyptus*	EC; GP; KZN; MP; NC; WC		2	3	Dec-Jan	PN
OLEACEAE							
Fraxinus sp.	Tree	EC; GP; KZN; MP; NC; WC			3	Aug-Oct	P
POLYGONACEAE							
Fagopyrum esculentum	Crop	EC; GP; KZN; WC	1			Jan-Feb	NP
PROTEACEAE							
Grevillea robusta	Tree	EC; GP; KZN; MP; WC	1			Oct-Nov	NP(x)
ROSACEAE							
Cotoneaster pannosus	Shrub	EC; GP; KZN; MP; NC; WC			3	Oct-Dec	NP
Prunus domestica	Crop	EC; GP; KZN; MP; NC; WC			3	Aug-Oct	PN
Prunus persica	Crop	EC; GP; KZN; MP; NC; WC			3	Jul-Sept	PN(x)

EXOTIC SPECIES LIST	Category	Province	Time Frame			Bloom	Resource
Rubus sp.	Weed	EC; WC	1			Oct-Dec	PN
RUTACEAE							
Citrus sp.	Crop	EC; GP; KZN; MP; NC; WC	1	2	3	Aug-Oct	NP
SAPINDACEAE							
Litchi chinensis	Crop	EC; GP; KZN; MP; NC; WC			3	Sept-Oct	NP
SOLANACEAE							
Nicotiana tabacum	Crop	GP; KZN; MP; WC	1			Oct-Mar	NP(x)
Physalis peruviana	Crop	GP	1			Jun-Sept	P
VERBENACEAE							
Petrea volubilis	Shrub	EC; GP; KZN; MP; NC; WC			3	Aug-Sept/Nov-Apr	NP

Forage Value Key *1:			
N:P →	Nectar and Pollen valued equally	N →	Nectar only source
NP →	Nectar valued over Pollen	P →	Pollen only source
PN →	Pollen valued over Nectar	(x) →	Indicated information unreliable

*1based after Johannsmeier (2001)

There were a number of crop species of significant use that were well represented across South Africa, two of which were recorded in all three time frames, namely *Helianthus annuus* and *Citrus sp*. The crop species *Persea americana*, *Prunus domestica*, *Prunus persica* and *Litchi chinensis*, although all three were only mentioned in last time frame, were also widely used across South Africa.

All but eight of the *Eucalyptus* species listed were distributed in all six regions of South Africa, indicating their general importance. Two of the four exotic shrub species listed were recorded in the third time frame as used in all six regions, but were not recorded in the two previous time frames. Seven of the 11 exotic tree species were distributed across all regions, most of which were recorded in the last time frame. Four of the five exotic weed species listed were recorded in the Western Cape, and only one *Bidens pilosa* was recorded in only Gauteng. *Hypochoeris radicata, Echium plantagineum* and *Raphanus raphanistrum* were all unique Western Cape forage species, and were only recorded in the last time frame.

Of the 62 exotic forage species listed, 40 (65%) were listed in the first time frame, 17 (27%) in the second time frame and 41 (66%) in the last time frame. The 27 *Eucalyptus* species were cited 21 times in the first time frame, 12 in the middle time frame and 20 times in the third time frame.

Of the 37 listed indigenous forage species only eight (22%) were listed in all regions of South Africa and were all, with the exception of one (*Protea sp*), also recorded in the third time frame. The family with the highest number of species used, Fabaceae, contained two species (*Acacia karroo* and *Schotia afra*) which were mentioned in the last time frame but also in all regions. Twelve indigenous species (32%) were listed in the first time frame, 3 species (8%) in the second time frame and 26 (70%) in the third time frame. Of these 26 mentioned species in third time frame, 21 (57%) were indigenous tree species.

Table 2.3: Indigenous species list, listing all significant indigenous forage species used. All species listed have been cited ≥3 times throughout the 90 year literature review. Grouped provincial regions include: GP – Gauteng/Free State/North West; MP – Mpumalanga/Limpopo. All bloom periods and forage resource data is as stated in literature sources reviewed. Provincial regions and time frame numbers in bold and shaded in grey indicate forage species that represent ≥5% of total citation number per time frame, and are thus considered the most significant forage sources in that particular provincial region.

INDIGENOUS SPECIES LIST	Category	Province	Time Frame			Bloom	Resource
AIZOACEAE							
Mesembrianthemum sp.	Shrub	GP; WC			3	Nov-Jan	NP
ANACARDIACEAE							
Sclerocarya birrea	Tree	EC; GP; KZN; MP; NC; WC			3	Sept-Oct	NP
Searsia lancea	Tree	EC; GP; KZN; MP; NC; WC			3	Jun-Jul	NP(x)
Searsia pyroides	Tree	GP; KZN; MP; NC;			3	Oct-Jan	N:P(x)
ASPARAGACEAE							
Asparagus sp.	Shrub	EC; GP; WC	1			Aug-Dec	N:P
ASPHODELACEAE							
Aloe greatheadii var. davyana	Shrub	GP; MP; NC		2	3	Jul-Aug	N:P
Aloe barberae	Tree	EC; KZN;			3	Apr-Jun	PN
Aloe marlothii	Tree	EC; GP; KZN; MP; NC; WC			3	Jun-Aug	PN
Aloe sp.	Shrub	EC; GP; MP			3	May-Nov	N:P
ASTERACEAE							
Arctotheca calendula	Weed	WC	1			Sept-Oct	PN
Brachylaena discolor	Shrub	GP; KZN; MP	1			Jul-Oct	NP
BIGNONIACEAE							
Tecomaiia capensis	Shrub	GP; KZN; MP; WC	1			Dec-Jan/Mar-Apr	PN
CANNABACEAE							
Celtis africana	Tree	GP; KZN	1			Aug-Oct	P(x)
CAPPARACEAE							

INDIGENOUS SPECIES LIST	Category	Province	Time Frame	Bloom	Resource
Boscia albitrunca	Tree	GP; KZN; MP; NC	3	Aug-Sept	N:P(x)
CELASTRACEAE					
Cassine peragua	Tree	EC; KZN; MP; WC	3	Jan-Jun	N:P
CUNONIACEAE					
Platylophus trifoliatus	Tree	EC; KZN; MP; WC	3	Dec-Feb	NP
ERICACEAE					
Erica sp.	Shrub	MP; WC	1	Mar-Jun	NP
FABACEAE					
Acacia caffra	Tree	GP; KZN; MP; WC	1	Sept-Oct	NP
Acacia erioloba	Tree	GP; NC	3	Aug-Nov	NP(x)
Acacia karroo	Tree	EC; GP; KZN; MP; NC; WC	3	Oct-Mar	N:P(x)
Acacia mellifera	Tree	GP; MP; NC	3	Jul-Nov	N:P
Dichrostachys cinerea	Tree	GP; KZN; MP; NC	3	Oct-Nov	NP(x)
Erythrina caffra	Tree	EC; GP; KZN; MP; NC	1 3	Jun-Sept	N:P
Schotia afra	Tree	EC; GP; KZN; MP; NC; WC	3	Nov-Jan	N:P
Schotia brachypetala	Tree	EC; GP; KZN; MP;	1 3	Sept-Oct	PN(x)
ICACINACEA					
Apodytes dimidiata	Tree	EC; KZN; MP; WC	3	Nov-Jan	PN
MALVACEAE					
Dombeya rotundifolia	Tree	GP; KZN; MP	2	Aug-Sept	PN
MYRTACEAE					
Syzgium cordatum	Tree	EC; GP; KZN; MP	3	Sept-Nov	NP
OLEACEAE					
Olea europaea africana	Tree	EC; GP; KZN; MP; NC	3	Nov-Jan	NP(x)
PROTEACEAE					

INDIGENOUS SPECIES LIST	Category	Province	Time Frame			Bloom	Resource
Faurea rochetiana	Tree	GP; KZN; MP			3	Apr-Jun	NP(x)
Faurea saligna	Tree	GP; MP	1	2		Nov-Dec	N:P(x)
Protea sp.	Shrub	EC; GP; KZN; MP; NC; WC	1			Oct-Jan	N:P(x)
RHAMNACEAE							
Scutia myrtina	Shrub	EC; GP; KZN; MP; NC; WC			3	Dec-Feb	NP
Ziziphus mucronata	Tree	EC; GP; KZN; MP; NC			3	Nov-Jan	NP
SAPINDACEAE							
Pappea capensis	Tree	EC; GP; KZN; MP; NC			3	Jan-Feb	N:P(x)
SCROPHULARIACEAE							
Buddleja saligna	Shrub	EC; GP; KZN; MP; NC; WC			3	-	-
Buddleja salviifolia	Shrub	EC; GP; KZN; MP; WC	1			Aug-Sept	NP(x)

Forage Value Key *1:			
N:P →	Nectar and Pollen valued equally	N →	Nectar only source
NP →	Nectar valued over Pollen	P →	Pollen only source
PN →	Pollen valued over Nectar	(x) →	Indicated information unreliable

*1based after Johannsmeier (2001)

Honeybee forage literature collated was not found to be consistent throughout the review period. Forage use data from time frame one was collected from a total of 65 articles, with one author (Loock 1949) of two articles contributing a total of 135 citations (the highest in this time frame). In the middle time frame there is a lack of data from *South Africa Bee Journals* articles and the studied literature, with only 46 articles providing forage data and as such there is no stand out author contribution. In time frame three (61 articles) there is one author (Johannsmeier, 1981, 1984, 1983, 1986, 1998, 2000, 2001, 2005, 2006, 2007) who contributes 15 articles as the sole author, and one article (Johannsmeier & Allsopp 1995) in which he is a co-author. Alone he contributes 404 (45%) citations and in the co-authored paper 193 citations (22%).

2.4. Discussion

2.4.1. *South African Bee Journal* Managed Honeybee Forage Review

This study shows that overall there is a solid source of honeybee forage knowledge in the literature of the *South African Bee Journal* (SABJ), but very limited in other published sources. In the three time frames that this literature review data was separated into, only in the second time frame (1950-1979) was there a lack of articles relating to honeybee forage. During this time it is believed that the South African Honeybee industry went through a decline, and although there is little evidence, it is speculated that there was little organisation amongst SABIO. This may have influenced the contributions of beekeepers and scientists, possibly resulting in a low number of honeybee forage related articles (Table 2.1) and species citations. The SABJ has proven to be a good source of honeybee forage knowledge in all regions of South Africa, which before this study had not been investigated. The SABJ identified a very diverse and broad range of flowering plant species that have been used by South African beekeepers at some point during the studied period (Table 2.1). However great the diversity of honeybee forage species identified in this study, the most significant forage category is *Eucalyptus*, which concurs with Johannsmeier & Mostert (2001).

2.4.2. Historically Important Forage Plants: Changes over Time

South African beekeepers have used a diverse range of forage species over the last 90 years, using both major and minor forage sources. In each provincial region there is a different forage usage pattern, as in each region different climatic conditions allow for different forage species to grow. Two forage categories have, however, remained strong in all regions, namely *Eucalyptus* and agricultural crop species, which play the most significant role throughout South Africa. As both of these categories are solely comprised of exotic species, it indicates that exotic species have remained the dominant forage source across South Africa throughout the past 90 years. Although indigenous species do play a role in providing minor forage sources to bridge the gap between major nectar and pollen flows, it is the exotic species that provide the dominant honeybee forage resource.

The literature indicates an increase in the usage, or more likely an increase in the reporting of use of indigenous species, as in the first and middle time frames indigenous species use is less reported on compared to the last time frame. This is especially true for the Eastern Cape and Northern Cape, where no indigenous species were recorded as used until the last 29 years. Many of the indigenous forage species recorded in the last time frame originate from a series of articles published in the SABJ that focused on South African indigenous tree species as honeybee forage, titled “Notes on trees as beeplants in South Africa” (Johannsmeier, 2007); this two part article listed indigenous tree species which are good honeybee forage. In addition to these articles, other indigenous forage citations came from a series of articles focused on the use of Aloe species as good forage sources. Articles such as “Bees on the Aloe fields: the quality of aloe nectar” (Human & Nicolson, 2007; 2008) and “The aloe flowering season” (Williams, 2002) emphasised the importance of aloes as an indigenous honeybee forage resource. Indigenous tree species that have been used extensively are the following: “*Acacia karroo*” “*Acacia caffra*” “*Searsia lancea*” “*Ziziphus mucronata*” “*Erythrina caffra*” “*Faurea saligna*”. These indigenous tree species have been extensively used across all regions of South Africa (Johannsmeier, 2007).

Although indigenous species are used throughout South Africa, it is the exotic species that play the most significant part in forage provision across all three time frames in South Africa. The literature is dominated with exotic forage species citations (Tables 2.3). *Eucalyptus* and crop species maintain their significance throughout, and where the literature is lacking in the middle time frame, the citations that have been recorded are mostly those of *Eucalyptus* and crop species. The crop species with the highest citation number, present in all regions are *Helianthus annuus* and *Citrus sp*., both of which are known to be favoured by honeybees (Greenleaf & Kremen, 2006; Hoopingarner & Waller, 2010).

This study reveals the significant role *Eucalyptus* species have played historically in the provision of forage to South African managed honeybee colonies. Similar findings are discussed in Allsopp & Cherry’s (2004) survey of Western Cape beekeepers and their reliance on certain *Eucalyptus* species. Throughout the 90 year review period *Eucalyptus* maintained a presence as a major forage provider throughout all regions of South Africa, where as other species have variable significance over time. Importantly six of these *Eucalyptus* species are listed under the Conservation of Agricultural Resources Act 1983

(Act 43 of 1983) as weeds and invader plants (CARA, 1983; NEMBA, 2004). *Eucalyptus camaldulensis*; *Euc. cladocalyx*; *Euc. conferruminata*; *Euc. diversicolor*; *Euc. grandis*; *Euc. tereticornis* are all listed under this Act of legalisation as either:

"*Category 2: Invasive species regulated by area. A demarcation permit is required to import, possess, grow, breed, move, sell, buy or accept as a gift any plants listed as Category 2 plants. No permits will be issued for Cat 2 plants to exist in riparian zones*" (NEMBA, 2004; CARA, 1983).

Or as "*Category 1b: Invasive species requiring compulsory control as part of an invasive species control programme. Remove and destroy. These plants are deemed to have such a high invasive potential that infestations can qualify to be placed under a government sponsored invasive species management programme. No permits will be issued*" (NEMBA, 2004; CARA, 1983).

The category allocated to each of these species is determined on the species geographic location in terms of its proximity to riparian areas (wetlands) or water catchment areas, and its location to high fire risk areas (Glazewski, 2005). If the species is deemed to be within a fire risk area or is located in a riparian zone it is categorised as a 1b and legally must be controlled and removed.

The six mentioned *Eucalyptus* species which are listed in the CARA legislation are all listed from this study as significant managed honeybee forage sources, and all the species excluding *Eucalyptus conferruminata* are listed as being present in all six provincial regions, and have been used by beekeepers extensively over the duration of this study's review time period (Table 2.2). Consequently the removal or control by removal of these species from across South Africa would reduce the available forage of a major source to South African beekeepers, with implication on the health and livelihood of managed honeybee colonies to perform pollination service. This has possible consequences on commercial agriculture, which could be without pollination service from managed beekeeping when a reduction of forage has a negative impact on managed beekeeping (vanEngelsdorp & Meixner, 2010; Ayers & Harman, 2010).

Whilst there are other *Eucalyptus* species that also play a role in significant forage provision, it is the diversity of forage species that leads to forage resource security, adequate forage comes from a diverse range of flowering plant sources (Ayers & Harman, 2010). Overall honeybee abundance is a positive function of the abundance of flowers in a particular habitat, such that habitats with abundant flowers have a greater possibility for partitioning of available pollen and nectar resources (Potts *et al.*, 2003), thus to ensure sufficient pollinators for agricultural crops its essential to maintain a healthy honeybee forage base. It is thus a range of exotic forage resources that are required in South Africa, further improved by occasional indigenous forage use.

2.4.3. Potential Caveats

A single literature source was almost entirely used to gather the majority of South African managed honeybee forage information, namely the *South African Bee Journal*, as other literature searches through similar literature sources revealed very poor to no honeybee forage information. As this method may have standardized the source data, it was a disadvantage in that the data collection was compromised in the middle time frame as there was a decline in the number of forage orientated articles that were published. This resulted in the middle time frame data being fairly poorly represented in comparison to the first and third time frames. As mentioned previously the 1950's-1970's there was a decline in the South African beekeeping industry and organizational body, this could be reasoned to be the cause of the lack of published foraged related articles. It does however relate the reality of the decline in the honeybee industry at the time, and recovery made subsequently.

As the SABJ is not a peer reviewed journal and the articles submitted came from a range of people, from hobbyist beekeepers to forestry researchers, the level of correct forage species information, such as names at times differed enormously. In the process of collecting and collating data from the literature, this study had to allocate family names to species which were not recorded with a family name. In the earlier decades, many of the cited species names have subsequently changed and much work was necessary to ensure all outdated names have been correctly changed, and family, genus, and species names are correctly stated in this study. The idea of using citizen scientists in the form of beekeeper forage information collected from the SABJ is, however, a well-used and understood method, when a study seeks to collect a large volume of data across a wide geographic area (Silvertown, 2009). However, correct forage species identification by "citizen scientists" can be questioned as there is no way of gauging whether species are correctly identified and thus this method does have its limitations.

2.5. Conclusion

Obtaining historic references to honeybee forage was challenging as only a single literature source provided any substantial forage literature. However data for 90 year time period did identify a diversity of both exotic and indigenous forage species.

Exotic forage species have been the dominantly used managed honeybee forage resource throughout the period covered by this review study. Although there has been good usage of indigenous forage species, their contribution does not outweigh the contribution made by exotic species to the South African beekeeping industry. The most important exotic forage source all belong to a single family Myrtaceae and are all *Eucalyptus* species. The most widely cited of these species being "*Eucalyptus grandis*" "*Eucalyptus melliodora*" "*Eucalyptus saligan*" and "*Eucalyptus sideroxylon*". Furthermore, a number of agricultural crop species were recorded to be significant forage sources, foremost of these being "*Helianthus annuus*" and "*Citrus sp*" both of which were recorded to be used heavily in all regions of South Africa.

The only significantly used indigenous forage source is *Aloe greatheadii var. davyana*. Whilst this review only reveals this single indigenous forage source as being of significance, it can however be speculated that *Aloe greatheadii var. davyana* was in fact used more substantially than which this study reveals, however lacking literature citations is likely to have resulted in this misrepresentation. A number of indigenous tree species where identified as important forage resources, the contribution of these species although not as significant as that of exotic tree species should not be dismissed. Indigenous forage species importance can be viewed in the contribution they make as minor sources which maintain honeybee colonies between the major forage flows and thus allowing colonies to benefit fully from the stronger flows.

This study reveals an increasing interest in the use of indigenous forage species. With pressure being applied towards the removal of certain exotic forage species, indigenous species contribution to the health and maintenance of South African managed honeybee colonies needs to be assessed. Although historic forage usage has been predominantly exotic, in order to ensure continued healthy managed colonies a more balanced usage of exotic and indigenous forage species should be considered.

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Chapter Three

FORAGE USE PATTERNS OF SOUTH AFRICAN BEEKEEPERS: WHICH FORAGE SPECIES ARE IMPORTANT TO MANAGED HONEYBEES?

3.1. Introduction

The honeybee, *Apis mellifera* is the most commonly managed pollinator in the world (vanEngelsdorp & Meixner, 2010) and is responsible for pollinating approximately 90% of the world's pollinator-dependant agricultural crops (Klein *et al.*, 2007). Recently there have been drastic declines in global managed honeybee populations (Meffe, 1998; Potts *et al.*, 2010) and consequently, concerns regarding the continued pollination of agricultural food crops have arisen throughout the world (Allen-Wardell *et al.*, 1998; Oldroyd, 2007; Neumann & Carreck, 2010). vanEngelsdorp and Meixner (2010) proposed potential causes of the currently seen global managed honeybee colony losses include factors such as honeybee pests and diseases, an example of which is the parasitic mite *Varroa* destructor and the bacterial disease American foulbrood (caused by the gram-positive bacterium *Paenibacillus*) (Ashiralieva & Genersch, 2006; Stankus, 2008). Alongside pests and diseases there are a number of abiotic factors which have a negative effect on honeybee populations such as poisons and pesticides, which can harm honeybees directly through poisoning as well as via the indirect route of sub-lethal doses which only become apparent after prolonged exposure (vanEngelsdorp & Meixner, 2010). Aside from the above factors, the loss and fragmentation of natural foraging habitats as well as forage resources for honeybees is having a drastic effect on honeybee population strengths (Kremen *et al.*, 2002), it is this factor upon which this study is focused.

The provision of adequate nectar and pollen resources on which honeybee colonies can forage is critical to sustaining managed honeybee colonies (Crailsheim, 1990; Dimou *et al.*, 2006; Shuel, 2010). Knowledge of the honeybee flora of an area is a basic tool for the development and sustainability of apiculture (Dimou *et al.*, 2006) and thus, in order to ensure sufficient pollinators for commercial agricultural crop pollination it is essential to identify key managed honeybee forage species as well as to maintain a healthy forage base of these species. The availability of adequate honeybee pasture has an impact on both beekeeping profitability and honeybee colony health (vanEngelsdorp & Meixner, 2010) as a decrease in forage availability leads to decreased productivity of honeybee colonies, which leads to colonies becoming more susceptible to pests and diseases. This subsequently decreases the profitability of a colony for the beekeeper (vanEngelsdorp & Meixner, 2010) and the ability for honeybee colonies to effectively pollinate agricultural crops.

Growing global demand for agricultural produce is causing the number of honeybee colonies depended upon to service the pollination demand to increase continuously (Aizen *et al.*, 2008; Godfray *et al.*, 2010). As economic and social development can be linked to strong food security (Godfray *et al.,* 2010), and food security can be achieved through agricultural crop pollination, the maintenance of strong honeybee colonies is essential. In order to build up and maintain strong honeybee colonies a number of factors need to be accomplished, forefront of which is ensuring honeybees have access to foraging habitats and suitable forage sources (Potts *et al.*, 2010). As such it is necessary to maintain and conserve forage resources across a range of sites, not all of which are in the close vicinity of agricultural landscapes, as commercial agricultural landscape often are associated with pesticides which as mentioned can have negative consequences for honeybee colonies (vanEngelsdorp & Meixner, 2010). An essential tool in controlling the decline in managed honeybee populations lies in efforts to preserve and protect landscapes that can provide suitable honeybee forage (Klein *et al.*, 2007; Naug, 2009), forage in such landscapes can also be enhanced through the planting of suitable forage species (Keasar & Shmida, 2008). An example of a forage enhancement project was implemented in Israel where by a nation-wide project of public tree planting was initiated for several reasons, such as the protection and improvement of environmental quality and for increased commercial timber production (Keasar & Shmida, 2008). The enhancement of forage for honeybees can be integrated into such a project via the planting of nectar and pollen yielding species, that also meet timber or environmental demand needs, thus a ‘win-win’ scenario is formed (Keasar & Shmida, 2008).

In South Africa, the two indigenous sub-species of honeybee are considered as keystone species due to the enormous contribution they make towards pollinating and sustaining a huge diversity of plant species (Johnson, 2004). South African honeybee populations, both managed and wild are also considered essential to South Africa's commercial agriculture (Allsopp & Cherry, 2004), as they are the only managed pollinators used to pollinate a variety of agricultural crops. The deciduous fruit industry for example is estimated to be worth R2.9 billion per annum (DAFF, 2011) and is heavily dependent on managed honeybees for pollination (Allsopp *et al.*, 2008), and a decline in honeybee pollinators would prove disastrous for this industry and many like it. In order to sustain South African honeybee pollinator populations, strong forage resources are necessary. The South African honeybee industry is sustained by a wide variety of plant forage species, though it has been suggested that without the introduction of several exotic forage species, the beekeeping industry of South Africa would not be as it is today (Johannesmeier, 2001). Honey production, for example, is made possible by *Eucalyptus* in South Africa; in the Western Cape alone, two-thirds of honey produced is produced on *Eucalyptus* (Allsopp & Cherry, 2004). *Eucalyptus cladocalyx* is one of the best nectar yielding vs in the Cape (May, 1969), and is said to be the number one honeybee forage species in South Africa. Not only do *Eucalyptus* species provide high quality nectar necessary for good honey production, they also play a critical role in strengthening honeybee colonies which can then be used for agricultural crop pollination. The South African honeybee industry also has a strong relationship with a number of agricultural crops, such as *Brassica napus* (Canola/Rape seed), which is used extensively by beekeepers in the spring to catch wild swarms (Langenhoven, 1999), as well as a valuable source of nectar and pollen. Other important agricultural crops associated with the South African honeybee industry include *Citrus* species, *Helianthus annuus* (sunflowers) and *Medicago sativa* (lucerne), all of which are used as valuable nectar and pollen sources (Johannesmeier, 2001). There are also a number of important weed species that play a role in providing honeybee forage, most of which are exotic species (Johannsmeier & Mostert, 2001).

Indigenous forage species which stand out in the South African honeybee literature include fynbos plant species found in the Western Cape (Hepburn & Guillarmod, 1991); specifically, species of *Erica* contribute the most towards honey production (Johannsmeier & Mostert, 2001). Species of Aloe provide an important winter forage for honeybees in the northern regions of South Africa (Human & Nicolson, 2008), as do species of indigenous trees, such as *Acacia karroo* (sweet thorn) and *Ziziphus mucronata* (buffalo thorn) (Johannsmeier & Mostert, 2001). *Aloe greatheadii var. davyana* is considered one of the most important indigenous South African bee plants (Johannsmeier & Mostert, 2001; Human & Nicolson, 2006) and is used extensively by beekeepers in northern Gauteng in the winter months as a strong source of nectar and pollen (Fletcher & Johannsmeier, 1978). The majority of indigenous forage species used in South Africa are minor forage sources used to maintain honeybee colonies between the major forage flows (Allsopp pers. comm., 2012).

Landscapes that are often disregarded as important foraging arenas for managed honeybees are urban environments, such as urban gardens. Samnegård *et al.* (2011) found that urban gardens are an important source of both floral resources and diversity, which provide pollinators with nesting sites and forage. Urban gardens thus increase pollinator abundance and pollinator species richness within their immediate surrounding area (Samnegård *et al.*, 2011), as well as supply a continuous supply of nectar and pollen which pollinators can use (Fussel & Corbet, 1992), demonstrating the positive impact urban gardens have on pollinators (Ahrné *et al.*, 2009). Samnegård *et al.* (2011) found evidence that suggests gardens also act as an important source of pollinators, as abundance of honeybees were found to be greater closer to urban gardens than further away and consequently gardens contributed to the ecosystem service of pollination in neighbouring agricultural landscapes. An aspect of this study investigates the value of natural and semi-natural habitats as havens for pollinators and if the promotion of such habitat should be encouraged.

South African forage resources need to be assessed and maintained on a regional scale as well as a national scale as the two indigenous South African sub-species of honeybee namely, *Apis mellifera capensis* (Cape honeybee) and *Apis mellifera sutellata* (African honeybee) (Hepburn & Radloff, 1998), are separated from one another by a naturally occurring hybrid zone (du Preez, 2010). The distribution of *A. mellifera capensis* roughly coincides with the distribution of the winter rainfall area of South Africa (Hepburn & Guillarmod, 1991) and *A. mellifera scutellata* is found north of the hybrid zone beyond the winter rainfall area (Hepburn & Radloff, 1998). As such sufficient forage resources cannot be concentrated in one area but need to be evenly distributed across all regions of South Africa as these two sub-species are not distributed uniformly across the country, and each requires sufficient forage to sustain it. The uneven distribution of sufficient quality forage would also hamper the profitability of beekeeping as the long distance transportation of managed honeybee colonies between forage resources would make beekeeping unprofitable.

Presently there are fewer threats to honeybees in South Africa than there are in other parts of the world (Neumann & Carreck, 2010; Strauss *et al.*, 2013), such as in the United States and parts of Europe, where colony declines are being experienced on a large scale (vanEngelsdorp & Meixner, 2010). However, honeybees still need to be conserved in order to ensure that similar colony losses are not repeated (Dietemann *et al.*, 2009), nevertheless in South Africa never before has forage usage been assessed, surveyed or monitored, and subsequently the proven knowledge of forage usage is unknown.

In this study I assess the threats facing the present honeybee forage usage in South Africa, through investigating the current forage usage. Habitat loss and subsequent forage loss is the most significant factor affecting wild and managed honeybee populations in Southern Africa (Dietemann *et al.*, 2009). Threatened forage resources are placing managed beekeeping under pressure to maintain apiary sites, as the loss of exotic forage species, predominately *Eucalyptus* through CARA legislation, is taking its toll. South African beekeepers rely on a diversity of forage species to maintain their colonies through the summer and winter months and a loss of suitable forage and/or apiary sites threatens to damage the South African honeybee industry (Johannsmeier, 2007). Allsopp and Cherry (2004) study revealed that 80% of all Western Cape managed honeybee colonies use exotic forage species at some point of the year and as such, the loss of such valuable forage resource will have serious implication in terms of agricultural crop pollination. In this study I assess the current managed honeybee forage species usage patterns in South Africa, identifying the relative reliance on exotic versus indigenous forage species, and ultimately I identify the most important forage species per provincial region based on the proportion of colonies supported.

3.2. Methods

Data to determine the current South African managed honeybee forage usage was collated from a national honeybee forage survey questionnaire. Information on the South African beekeeping industry, with respect to total numbers of hives, was also collated from the distributed questionnaire.

3.2.1. South African Honeybee Forage Questionnaire

A South African honeybee forage questionnaire was designed specifically for South African beekeepers and the South African beekeeping industry after extensive debate with beekeepers, ecosystem services researchers, and invasive species ecologists in September – October 2011. The questionnaire was designed and subsequently released in December 2011, and was promoted until September 2012 (eight months). The key focus of the questionnaire was aimed at collecting forage species use data in order to assess the current forage usage trends in South Africa. Such data currently does not exist in South Africa, as beekeepers are not required through legislation to keep official records. Many beekeepers consider their forage usage to be a highly sensitive subject and would rather not divulge such information. As such, the questionnaire was designed so that beekeepers would not be required to divulge precise location of their apiary sites, but rather give an indication of the closest town to each site. In this way, the data could then be divided into provincial areas, based on the closest town given.

A public dissemination program, which included journal articles published in the *South African Bee Journal* (SABJ), presentations at Beekeeper Association meetings and a general awareness campaign preceded the release of the questionnaire, prevailing on beekeepers nationally to complete the questionnaire, and appealing to them to make contact if they did not receive the questionnaire, or if they had any concerns or questions. This program was also used to explicitly explain the purpose of the study, as well as assure all beekeepers that the questionnaire was a completely confidential exercise, whereby no individual questionnaire information would be released or published in any form.

The questionnaire was designed to be as “user friendly” as possible whilst still being able to gather the maximum amount of information needed. The questionnaire was designed to collect information for both this MSc study and a related PhD study. It was decided that instead of releasing multiple questionnaires to collect forage information, that a single questionnaire would be released in collaboration between the two studies. Asking beekeeper to complete one questionnaire was thought likely to generate a better response than requiring a response from two separate questionnaires on related topics. As this study only covers a portion of the questionnaire content, this methods section only describe the content applicable.

A list of 58 forage species was published in the questionnaire, with seven, regional generic vegetation types additionally listed. The 58 forage species were listed in categories, namely: *Eucalyptus*, 13 species; Crops, 14 species; Trees, 12 species; Shrubs, succulents, herbs, 13 species; Weeds, 6 species. The seven regional generic vegetation types were the following: Suburban Gardens; Indigenous Forests; West Coast Fynbos/Strandveld; South Cape Strandveld; Mountain Fynbos; Karoo (Including Nama and Succulent Karoo); Bushveld. These forage species were chosen based on their known status as managed honeybee forage species, used in various regions of South Africa. Each species has been listed as important forage (Johannsmeier, 2005) and was recommended by the ARC Honeybee Research Unit as a significant forage sources (Mike Allsopp pers. comm., 2011). The questionnaire forage species list did not discriminate against either indigenous or exotic species. At the end of the species and generic regional vegetation list an “Other” section was published, which allowed beekeepers to add forage species which they use and were not listed in the printed species list. The final questionnaire draft, once complete, was trialed by two well-known commercial beekeepers in order to assess whether the design and layout of the questionnaire would result in the desired information to be collected. The feedback from these beekeepers was analysed and final edits to the questionnaire design were made in order to address all comments.

The questionnaire also aimed at collecting additional information with regards to the individual beekeepers. This information included: (1.) Beekeeper provincial location; (2.) Number of honeybee colonies maintained by beekeeper. No information on precise location of apiary site or individual colony usage per forage source was investigated. For this study, data was collected and is analysed on a provincial scale only.

The questionnaire was distributed nationally in South Africa and was targeted at all South African beekeepers, regardless of whether a beekeeper kept honeybees on a hobbyist or commercial basis. South African beekeepers are required through legislation to be registered with a central agricultural organization, but this requirement is often ignored by beekeepers, and has not been enforced by the State. In addition, beekeepers in South Africa have never been inspected or audited. As a result of this, no central database of beekeepers or beekeeping exists and no data relating to the exact number of beekeepers exists for South Africa. Therefore, in order to ensure the questionnaire was received and completed by as many South African beekeepers as possible, the questionnaire was distributed via multiple channels. The forage questionnaire was firstly distributed as a hardcopy, both in English and Afrikaans, with a postage paid return addressed envelope within the December 2011 edition of the *South African Bee Journal* (Volume 83 No. 4) which is a quarterly published journal that is distributed to all registered South African Bee Organization (SABIO) members, as well as to all other known beekeepers. SABIO is the South African beekeeping industry central organization. Questionnaires were also distributed via two voluntary South African beekeeper email groups (19 January 2012); namely: (1) BeeSAGoogle Group (beessa@googlegroups.com), and; 2. ApicultureSA Group (apiculture-sa@googlegroups.com). These two email groups both have large followings from South African beekeepers and are well represented. In this case beekeepers were asked to complete the questionnaires and return via email. Overall, it was felt that the questionnaire was distributed widely and that the majority of South African beekeepers were made aware of the study and had received a copy of the questionnaire.

In addition to the two discussed methods of questionnaire distribution, oral presentations were given at four provincial Beekeeper Association meetings, as well as at the annual SABIO BEECON (South African Bee Industry Organisation Bee Conference, Gauteng; 15 June 2012), in order to relay to the South African beekeeping industry and all its members the purpose of this study and the reasoning behind why it was important for them to complete and return the questionnaire. Beekeeper Association meetings attended included: Southerns Beekeeping Association meeting (Gauteng; 13 April 2012); KwaZulu Natal Beekeeper Association meeting (KwaZulu Natal; 17 March 2012); Easterns Beekeeper Association meeting (Gauteng; 17 March 2012); and Vhembe Beekeeper Association meeting (Limpopo; 22 March 2012). All presentations were met with good response and increased the response rate of the questionnaires. The final bid to ensure a good response rate was performed in the form of telephone calls made directly to known commercial beekeepers who had as yet not returned their questionnaire. In some cases, beekeepers politely declined from responding, while others were grateful for the telephonic reminder and completed and returned their questionnaires via email or postal service.

As questionnaire responses were returned, the information of each completed questionnaire was entered into a series of Microsoft Excel data sheets. In some instances questionnaires were not correctly completed or information was omitted. Where possible these individual beekeepers where contacted via email or telephonically and asked for the correct information.

The post-response evaluation of the survey indicated that the questionnaire was in general conscientiously and accurately answered. In some cases, however, species names when supplied where out dated, and in a few instances, critical information was omitted.

3.2.2. Data Analysis

Data relating to species usage was extracted and listed. All species were classed under the following categories: (1) *Eucalyptus*; (2) Crop: (3) Shrubs, which included succulents, herbs, and grasses (from here on to be referred to as "Shrub"); (4) Tree; (5) Weed; and (6) Regional Generic vegetation type. Over and above the original 58 forage species that were listed as part of the questionnaire, all "Other" species were additionally added to the above mentioned categories, according to their growth form, species or agricultural use. Where additional Regional Generic vegetation groups were listed as "Other", they were either listed as a new vegetation group or added to an already existing one, depending on floristic similarities.

Data analysis was performed in a similar manner as in Chapter Two. This was in order to enable a comparison between the historic data and current data. The collated information was divided into the six provincial regions that were used in Chapter Two; namely: Western Cape; Northern Cape; Eastern Cape; KwaZulu Natal; Mpumalanga and Limpopo combined; and Free State, Gauteng and North West combined. Mpumalanga and Limpopo, and the Free State, Gauteng and North West provinces, respectively, were combined as they broadly share similar vegetation characteristics.

Plant forage species used by individual beekeepers in each provincial region were compressed into a regional forage list. When multiple entries of the same species occurred, the number of colonies of each entry was added to give the total number of colonies using each forage species. As colonies use multiple forage species at different stages of the year, the percentage use of each forage species do not equate to 100%. All forage species in each provincial region were ranked by importance, taken as the percentage of a region's colonies that are supported by a forage species. Forage species lists excluded all forage species that did not provide forage for at least 10% of a region's colonies. The numbers of forage species used relative to the number of these that were significant forage species could thus be compared between forage categories and regions.

3.3. Results

3.3.1. Percentage Return of Questionnaire

A total of 1400 hardcopy questionnaires (English and Afrikaans) were sent out to South African beekeepers via the *South African Bee Journal* in December 2011 (SABJ Volume 83 No. 4). As additional questionnaires were distributed electronically, both via email and posted on the South African Bee Industry Organisation (SABIO) website, the exact number of distributed questionnaires is unknown, but is estimated to be approximately 3000. In total 219 responses were received back from beekeepers that accounted for 50 067 managed honeybee colonies. A census of the number of managed honeybee colonies in South Africa has not been accurately collected in recent time. However, Allsopp and Cherry (2004) estimated that there were respectively 40 000 and 120 000 managed honeybee colonies in the Western Cape and South Africa at the time of their survey. This estimation is based on data collected for their study of the Western Cape honeybee industry, and the relative contribution of the Western Cape to national honey production, and cannot be assumed to be the absolute number of South African colonies. If however the response rate for this survey were to be based on the Allsopp and Cherry (2004) estimation, this study represents 41.72% of South Africa's managed honeybee colonies.

The best represented provincial region was the Western Cape where beekeepers responses covered 23 157 colonies (46.25%; Table 3.6), the least represented provincial region was the Free State/Gauteng/North West with only 3597 (7.18%) honeybee colonies (Table 3.2).

3.3.2. Provincial Vegetation Type Usage

Regional vegetation types differed in each provincial region (Appendix II), the only vegetation type which appeared consistently in all six provincial regions was "Suburban Gardens" which potentially would comprise of mostly exotic plant species. In three provincial regions, suburban gardens were of high importance, with ≥10% of the colonies using Suburban Gardens - Free State/Gauteng/North West (22.94%), Mpumalanga/Limpopo (21.63%), and Western Cape (17.15%). The Eastern Cape colonies relied heavily on Eastern Cape Thicket as a forage source, with 27.28% of Eastern Cape colonies using this source at some point during the year. In addition to Suburban Gardens, the Free State/Gauteng/North West colonies used Bushveld heavily (35.03%). Mpumalanga/Limpopo honeybee colonies used Indigenous Forests extensively (24.15%) as well as Suburban Gardens (21.63%). The Northern Cape had only one vegetation type Karoo, upon which nearly all colonies (89.90%) foraged. The Western Cape honeybee colonies had the highest diversity of regional generic vegetation types, in rank order of significance: Mountain Fynbos (35.04%); Strandveld (28.98%); Coastal Fynbos (27.92%); Suburban Gardens (17.15%); and Karroo (12.42%) (Appendix II).

3.3.3. Exotic and Indigenous Forage Usage

The distributed questionnaire listed 58 forage species and seven regional generic vegetation types; however, a final total of 91 forage species (33 additional) and nine regional generic vegetation types (two additional) were used in the final analyses. The Western Cape had the highest forage species diversity with 59 species, 20 indigenous and 39 exotic (Fig. 3.2). The Free State/Gauteng/North West provincial area also had a high forage species diversity of 51 species, (18 indigenous and 33 exotic) (Fig. 3.1). The lowest forage species diversity was KwaZulu Natal with only 17 species (five indigenous and 12 exotic) (Fig. 3.1), although this province had the second highest colony representation, 8448 (Table 3.3).

Exotic and indigenous forage species were both used by managed honeybees throughout South Africa, but the level of dependence differed in each provincial region.

In total 4329 managed honeybee colonies were represented in the Eastern Cape (Table 3.1), the majority (88.06%) of which foraged on *Eucalyptus* species at a point during the year (Figure 3.3). The most important identified exotic forage species in the Eastern Cape was *Eucalyptus grandis*, which was used as a forage source by 86.39% of the colonies, important Crop species within the Eastern Cape included *Citrus spp.* (29.11%) and *Persea Americana* (23.10%; Table 3.1). Additionally two *Eucalyptus* species are relied upon heavily, namely *Eucalyptus cladocalyx* (24.53%) and *Eucalyptus sideroxylon* (23.10%) (Table 3.1). The two most important indigenous forage species in the Eastern Cape were the tree species, *Acacia karroo* (69.07%), and the shrub *Scutia myrtina* (57.75%; Table 3.1). There was also a strong contingent of both indigenous shrub species (seven species; 81.10%) and indigenous tree species (six species; 88.70%) (Fig.3.1). The exotic tree and weed forage species were of little importance with <10% of hives using them. The Eastern Cape had a similar number of exotic (15 species) and indigenous (13 species) forage species; however fewer of these where of importance (species upon which ≥10% honeybee colonies forage).

Out of 15 exotic forage species only five species were of importance and only two of the indigenous species were used by ≥10% of EC colonies (Fig. 3.1; Table 3.1).

The Free State; Gauteng and North West provincial regions represented 3597 managed honeybee colonies (Table 3.2) and has a strong reliance on the nine *Eucalyptus* species used as forage (Fig. 3.1; Table 3.2). In total 51 forage species are used, of which 18 are indigenous and 33 exotic (Fig. 3.1). Of these indigenous forage species, only eight of the 18 are of importance, and 12 of the 33 exotic species are of importance (Fig. 3.1; Table 3.2). The most important exotic forage source is *Eucalyptus paniculata* (56.60%) followed by *Eucalyptus sideroxylon* (42.81%) and *Eucalyptus grandis* (39.64; Table 3.2). Crop and *Eucalyptus* species contribute five important forage species to the forage resource of this region (Fig. 3.1). The most important indigenous tree species was *Ziziphus mucronata* (53.91%). Indigenous forage species that contribute a significant amount of forage include *Acacia caffra* (41.31%), *Acacia mellifera* (35.03%), and *Aloe greatheadii subsp davyana* (30.86%; Table 3.2). Three weed species provide significant forage, *Raphanus raphanistrum* (32.25%), *Biden Formosa* (29.27%) as well as the indigenous weed species *Senecio apiifolius* (25.94%) (Table 3.2). There are also 13 crop species, including five species of importance (Fig. 3.1). There is a strong indigenous tree forage resource represented by 10 tree species. Exotic weed species are also important with a diversity of six species, two of which are important (Fig. 3.1). There are seven indigenous Shrub species, but these do not support a significant number of colonies (Fig. 3.1).

KwaZulu Natal is represented by 8448 managed honeybee colonies (Table 3.3) and is almost completely reliant on *Eucalyptus* and crop species as a forage resource (Fig. 3.1). Two *Eucalyptus* species, *Eucalyptus grandis* (99.75%) and *Eucalyptus sideroylon* (47.35%) were matched with two crop species, *Citrus spp.* (87.61%) and *Helianthus annuus* (82.86%) (Table 3.3). Ten crop and two *Eucalyptus* species supported all of these colonies (Figure 3.1). KwaZulu Natal honeybee forage was comprised of 17 species in total, of which there were only four forage species of high importance, all of which were exotic (Figure 3.1; Table 3.3).

The Mpumalanga and Limpopo region was represented by 4974 managed honeybee colonies (Table 3.4), and has a heavy reliance on crop forage species. The highest ranked of the 13 exotic species was *Eucalyptus grandis* (75.31%) followed by the crop *Persea americana* (63.76%; Table 3.4). The highest ranked crop species were *Macadamia spp.* (56.27%), *Litchi spp*. (55.40%), *Citrus spp*. (35.56%), and *Magnifera spp*. (25.48%; Table 3.4). The highest ranked indigenous species was *Aloe marlothii* (32.44%) and *Acacia karroo* (28.98%). One indigenous weed species was of importance, *Senecio apiifolius* (20.12%), as well as a single shrub species *Aloe greatheadii davyana* (21.80%; Table 3.4). There are in total 15 important crop species and 11 indigenous shrub species. Indigenous shrub and weed species play an important role in providing forage (Fig. 3.2). This provincial region has 38 honeybee forage species in total; of the 15 indigenous species only nine, which included six tree species, were of significance (Fig. 3.2; Table 3.4). In total, 23 exotic forage species were recorded (Fig. 3.2). Of these, 13 were classed as being of importance and comprised of 11 crop species, and two *Eucalyptus* species (Fig. 3.2).

The Northern Cape has 5562 managed honeybee colonies (Table 3.5). The highest ranked species are indigenous tree species, *Acacia mellifera* (98.74%) and *Acacia karroo* (98.63%; Table 3.5). Of the eight important exotic species only three are *Eucalyptus* species (Table 3.5): *Eucalyptus camaldulensis*, *Eucalyptus melliodora*, and *Eucalyptus sideroxylon,* all of which are foraged upon by 89.90% of the Northern Cape colonies. The highest ranked crop species is *Medicago sativa* (96.30%; Table 3.5). There is a good indigenous tree forage base of eight species, where there are only two exotic tree species of importance (Fig. 3.2). The three *Eucalyptus* species and four crop species play a similar role in providing a solid forage resource (Fig. 3.2). The Northern Cape forage resource comprises of 21 honeybee forage species. Of these species, 20 are indigenous species of which seven are important (Table 3.2). Ten exotic species are used, of which eight are of importance (Fig. 3.2). All 15 important forage species in the Northern Cape have high colony usage percentage, all ≥89.90% (Table 3.5).

The Western Cape honeybee forage resource comprises of the highest diversity of forage species (59 species) in the country, as well as representing 23 157 managed honeybee colonies (Fig. 3.2; Table 3.6). The highest ranked honeybee forage species in the Western Cape is *Eucalyptus cladocalyx* (78.98%) followed by the crop species *Brassica napus var. olifera* (77.19%). *Echium plantagineum* is an important weed species providing forage for 40.89% of the colonies (Table 3.6). Indigenous honeybee forage species comprise of 20 species, of which five are important (Fig. 3.2). The highest ranked of these is the succulent *Mesems spp.* (29.58%) and a diversity of *Erica* species (22.08%). The only indigenous tree species of importance is *Acacia karroo* (15.91%) (Table 3.6). Crop (17 species) and *Eucalyptus* (13 species) play the most substantial role in providing forage in this region. There are however a solid base of Indigenous shrub species (14 species) as well as important exotic weed species (four species; Fig. 3.2). However, only 17 of the 39 exotic species are of importance and five of the 20 indigenous species (Fig. 3.2) play an important role in providing forage for ≥10% of the Western Cape colonies (Figure 3.2). In total there are seven species of *Eucalyptus* (out of 13) that are important forage sources, as well as eight crop species (out of 17) (Fig. 3.2).

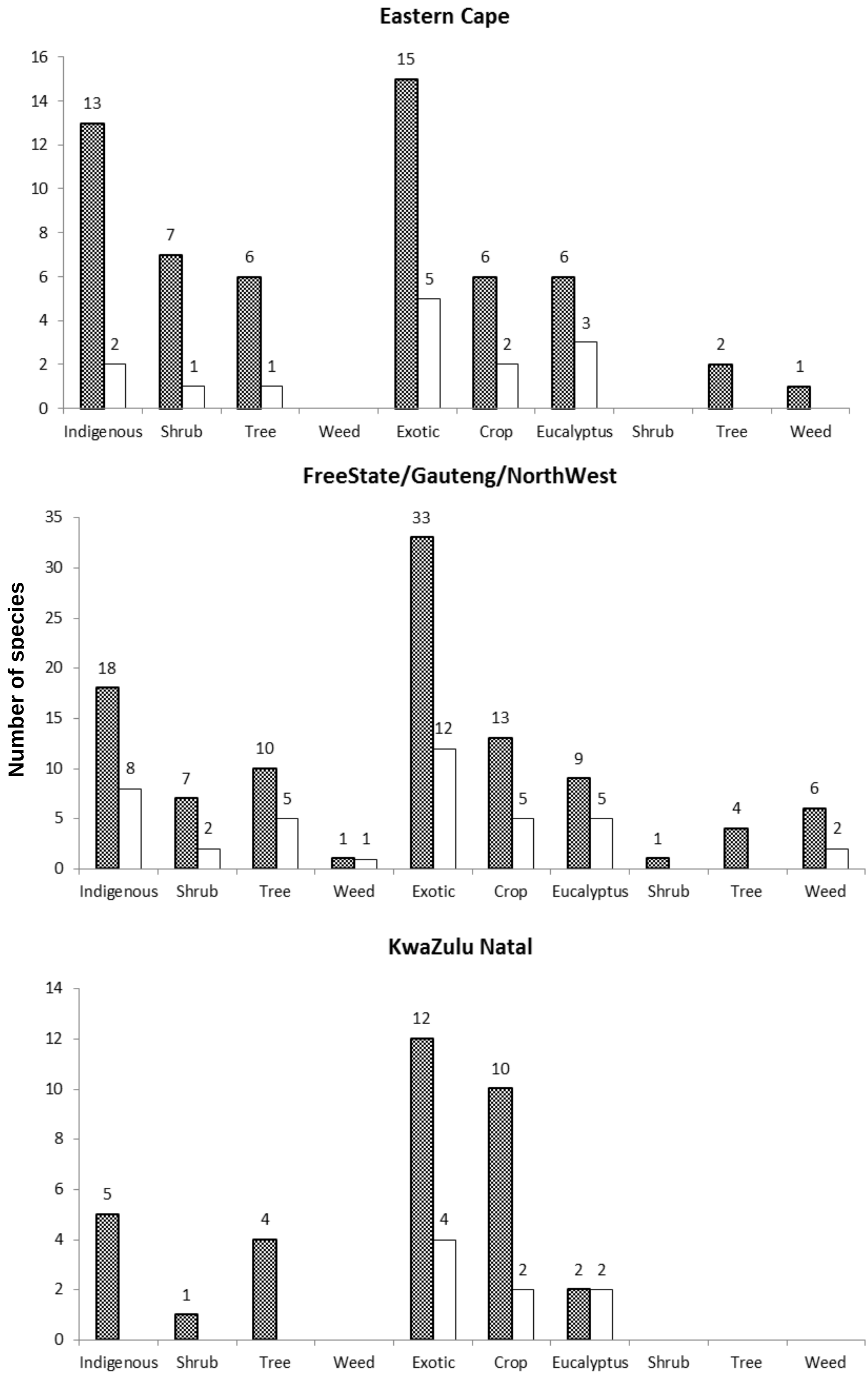

Figure 0.1: Provincial forage species breakdown per indigenous and exotic category. Number of species used per category (shaded) and number of significant species (species used by ≥10% of provincial colonies) used per category (clear).

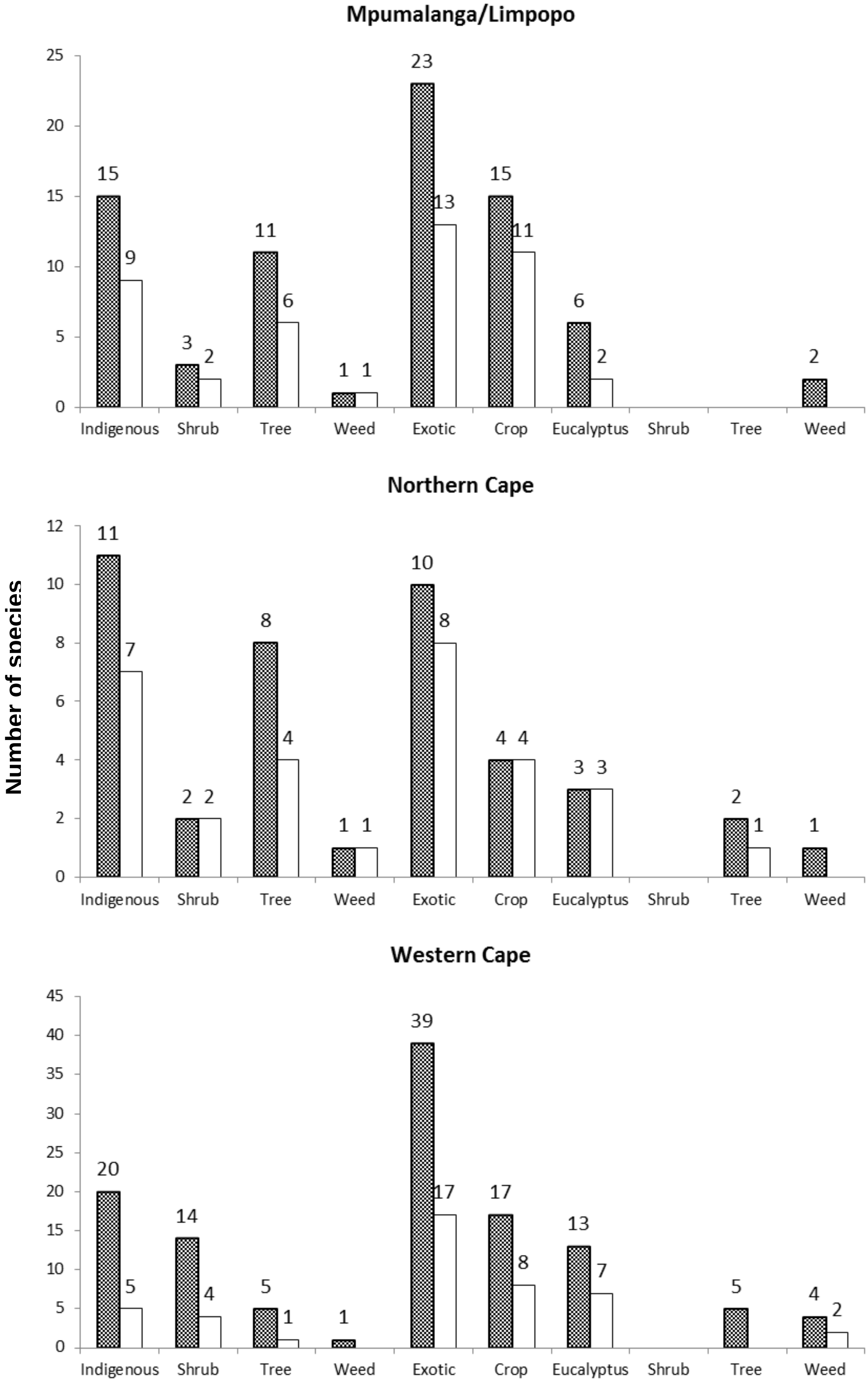

Figure 0.2: Provincial forage species breakdown per indigenous and exotic category., Number of species used per category (shaded) and number of significant species (species used by ≥10% of provincial colonies) used per category (clear).

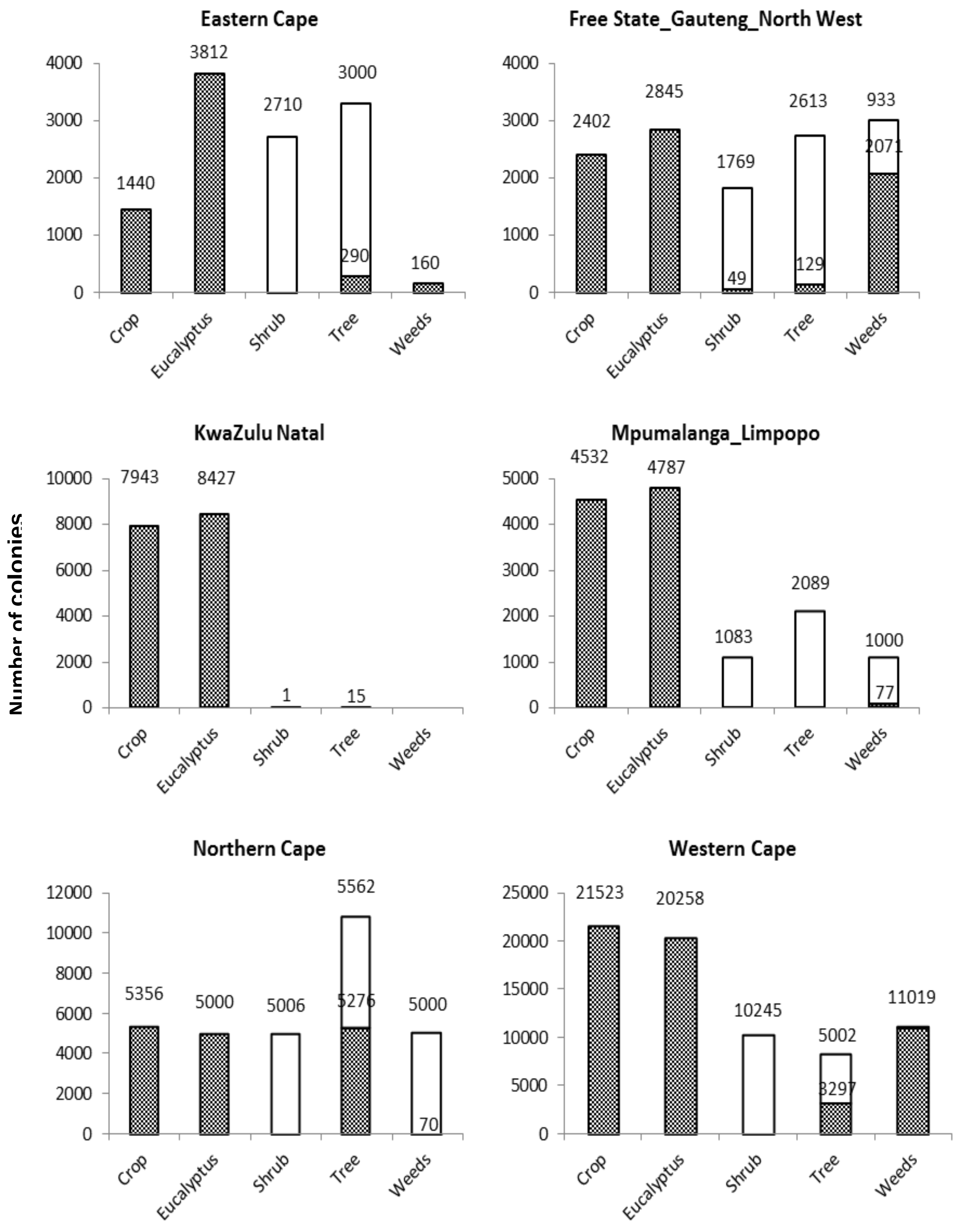

Figure 0.3: South African provincial regions forage usage make up, represented by number of managed honeybee colonies using each forage category. Shaded (exotic) and clear (indigenous) bars represent number of managed honeybee colonies using exotic/indigenous species in each category.

Table 0.1: Eastern Cape honeybee forage species list, including only the species that provide forage for 10% or more of managed honeybee colonies in this provincial region. Eastern Cape represents 4329 managed honeybee colonies.

#	Family name	Scientific name	Common name	%	Status	Category
1	Myrtaceae	*E. grandis*	Saligna gum	86.39	Ex	*Eucalyptus*
2	Fabaceae	*Acacia karroo*	Sweet thorn	69.07	In	Tree
3	Rhamnaceae	*Scutia myrtina*	Cat thorn	57.75	In	Shrubs
4	Rutaceae	*Citrus spp.*	Citrus	29.11	Ex	Crop
5	Myrtaceae	*E. cladocalyx*	Sugar gum	24.53	Ex	*Eucalyptus*
6	Myrtaceae	*E. sideroxylon*	Blackironbark	23.10	Ex	*Eucalyptus*
7	Lauraceae	*Persea americana*	Avocado	23.10	Ex	Crop

Table 0.2: Free State/Gauteng/North West honeybee forage species list, including only the species that provide forage for 10% or more of managed honeybee colonies in this provincial region. Free State/Gauteng/North West represents 3597 managed honeybee colonies.

#	Family name	Scientific name	Common name	%	Status	Category
1	Myrtaceae	*E. paniculata*	Grey ironbark	56.60	Ex	*Eucalyptus*
2	Rhamnaceae	*Ziziphus mucrononata*	Buffalo thorn	53.91	In	Tree
3	Myrtaceae	*E. sideroxylon*	Black ironbark	42.81	Ex	*Eucalyptus*
4	Mimosoideae	*Acacia caffra*	Common hook thorn	41.31	In	Tree
5	Myrtaceae	*E. grandis*	Saligna gum	39.64	Ex	*Eucalyptus*
6	Mimosoideae	*Acacia mellifera*	Hook thorn	35.03	In	Tree
7	Brassicaceae	*Raphanus raphanistrum*	Wild radish	32.25	Ex	Weed
8	Asphodelaceae	*Aloe greatheadii subsp davyana*	Spotted aloe	30.86	In	Shrub
9	Asteraceae	*Bidens formosa*	Cosmos	29.27	Ex	Weed
10	*Proteaceae*	*Macadamia spp.*	Macadamia	29.05	Ex	Crop
11	Asteraceae	*Helianthus annuus*	Sunflower	28.13	Ex	Crop
12	Curcubitaceae	*Cucurbita spp.*	Pumpkin	27.80	Ex	Crop
13	Rutaceae	*Citrus spp.*	Citrus	26.47	Ex	Crop
14	Myrtaceae	*E. melliodora*	Yellow box gum	26.08	Ex	*Eucalyptus*
15	Asteraceae	*Senecio apiifolius*	Winter weed	25.94	In	Weed
16	Myrtaceae	*E. camaldulensis*	River red gum	22.21	Ex	*Eucalyptus*
17	Anacardiaceae	*Searsia lancea*	Karee	19.29	In	Tree
18	Mimosoideae	*Acacia karroo*	Sweet thorn	15.40	In	Tree
19	Rutaceae	*Agathosma spp.*	Buchu	13.90	In	Shrub
20	Fabaceae	*Medicago sativa*	Lucern	10.01	Ex	Crop

Table 0.3: KwaZulu Natal honeybee forage species list, including only the species that provide forage for 10% or more of managed honeybee in this provincial region, KwaZulu Natal represents 8448 managed honeybee colonies.

#	Family name	Scientific name	Common name	%	Status	Category
1	Myrtaceae	*E. grandis*	Saligna gum	99.75	Ex	*Eucalyptus*
2	Rutaceae	*Citrus spp.*	Citrus	87.61	Ex	Crop
3	Asteraceae	*Hellianthus annuus*	Sunflower	82.86	Ex	Crop
4	Myrtaceae	*E. sideroxylon*	Black ironbark	47.35	Ex	*Eucalyptus*

Table 0.4: Mpumalanga/Limpopo honeybee forage species list, including only the species that provide forage for 10% or more of managed honeybee colonies in this provincial region. Mpumalanga/Limpopo represents 4974 managed honeybee colonies.

#	Family name	Scientific name	Common name	%	Status	Category
1	Myrtaceae	*E. grandis*	Saligna gum	75.31	Ex	*Eucalyptus*
2	Lauraceae	*Persea americana*	Avocado	63.76	Ex	Crop
3	Anacardiaceae	*Macadamia spp.*	Macadamia	56.27	Ex	Crop
4	Sapindaceae	*Litchi spp.*	Litchi	55.40	Ex	Crop
5	Rutaceae	*Citrus spp.*	Citrus	35.56	Ex	Crop
6	Asphodelaceae	*Aloe marlothii*	Mountain Aloe	32.44	In	Tree
7	Myrtaceae	*E. camaldulensis*	River red gum	32.20	Ex	*Eucalyptus*
8	Mimosoideae	*Acacia karroo*	Sweet thorn	28.98	In	Tree
9	Anacardiaceae	*Magnifera spp.*	Mango	25.48	Ex	Crop
10	Asphodelaceae	*Aloe greatheadii subsp davyana*	Spotted aloe	21.80	In	Shrub
11	Anacardiaceae	*Searsia lancea*	Karee	21.13	In	Tree
12	*Proteaceae*	*Faurea saligna*	Bushveld boekenhout	20.47	In	Tree
13	Asparagaceae	*Asparagus spp.*	Wild asparagus	20.12	In	Shrub
14	Combretaceae	*Combretum spp.*	Bushwillow	20.12	In	Tree
15	Asteraceae	*Senecio apiifolius*	Winter weed	20.12	In	Weed
16	Rhamnaceae	*Ziziphus mucronata*	Buffalo thorn	20.12	In	Tree
17	Brassicaceae	*Brassica napus var. oleifera*	Canola	12.88	Ex	Crop
18	Poaceae	*Saccharum spp.*	Sugar-cane	12.28	Ex	Crop
19	Fabaceae	*Medicago sativa*	Lucerne	12.07	Ex	Crop
20	Myrtaceae	*Psidium guajava*	Guava	12.07	Ex	Crop
21	Rosaceae	*Rubus idaeus*	Raspberry	12.07	Ex	Crop
22	Vitaceae	*Vitis vinifera*	Grape	12.07	Ex	Crop

Table 0.5: Northern Cape honeybee forage species list, including only the species that provide forage for 10% or more of managed honeybee colonies in this provincial region. Northern Cape is represented by 5562 managed honeybee colonies.

#	Family name	Scientific name	Plant name	%	Status	Category
1	Mimosoideae	*Acacia mellifera*	Hook thorn	98.74	In	Tree
2	Mimosoideae	*Acacia karroo*	Sweet thorn	98.63	In	Tree
3	Fabaceae	*Medicago sativa*	Lucerne	96.30	Ex	Crop
4	Fabaceae	*Prosopis spp.*	Mesquite	94.75	Ex	Tree
5	Rhamnaceae	*Ziziphus mucronata*	Buffalo thorn	93.49	In	Tree
6	Aloaceae	*Aloe grandidentata*	Kanniedood	90.00	In	Shrub
7	Fabaceae	*Acacia tortilis*	Umbrella thorn	89.90	In	Tree
8	Amaryllidaceae	*Allium cepa*	Onion	89.90	Ex	Crop
9	Curcubitaceae	*Cucurbita spp.*	Pumpkin	89.90	Ex	Crop
10	Myrtaceae	*E. camaldulensis*	River red gum	89.90	Ex	*Eucalyptus*
11	Myrtaceae	*E. melliodora*	Yellow box gum	89.90	Ex	*Eucalyptus*
12	Myrtaceae	*E. sideroxylon*	Black ironbark	89.90	Ex	*Eucalyptus*
13	Asteraceae	*Helianthus annuus*	Sunflower	89.90	Ex	Crop
14	Asteraceae	*Senecio apiifolius*	Winter weed	89.90	In	Weed
15	Zygophyllaceae	*Zygopyllum spp.*	Skilpadsbos spp.	89.90	In	Shrub

Table 0.6: Western Cape honeybee forage species list, including only the species that provide forage for 10% or more of managed honeybee colonies in this provincial region. Western Cape is represented by 23157 managed honeybee colonies.

#	Family name	Scientific name	Common name	%	Status	Category
1	Myrtaceae	*E. cladocalyx*	Sugar gum	78.98	Ex	*Eucalyptus*
2	Brassicaceae	*Brassica napus var. oleifera*	Canola	77.19	Ex	Crop
3	Boraginaceae	*Echium plantagineum*	Echium	40.89	Ex	Weed
4	Myrtaceae	*E. camaldulensis*	River red gum	33.50	Ex	*Eucalyptus*
5	Rosaceae	*Malus domestica*	Apple	32.98	Ex	Crop
6	Fabaceae	*Medicago sativa*	Lucerne	32.91	Ex	Crop
7	Mesembryanthemaceae	*Mesems*	Mesems	29.58	In	Shrub
8	Brassicaceae	*Raphanus raphanistrum*	Wild radish	28.96	Ex	Weed
9	Rutaceae	*Citrus spp.*	Citrus	23.10	Ex	Crop
10	Ericaceae	*Erica spp.*	Erica spp.	22.08	In	Shrub
11	Myrtaceae	*E.gomphocephala*	Tuart gum	19.74	Ex	*Eucalyptus*
12	Myrtaceae	*E. grandis*	Saligna gum	19.26	Ex	*Eucalyptus*
13	*Proteaceae*	*Protea spp.*	Protea spp.	18.62	In	Shrub
14	Myrtaceae	*E. sideroxylon*	Black ironbark	16.94	Ex	*Eucalyptus*

#	Family name	Scientific name	Common name	%	Status	Category
15	Brassicaceae	*Brassica spp.*	Cabbage	16.64	Ex	Crop
16	Rutaceae	*Agathosma spp.*	Buchu	16.59	In	Shrub
17	Rosaceae	*Prunus spp.*	Plum	15.99	Ex	Crop
18	Mimosoideae	*Acacia karroo*	Sweet thorn	15.91	In	Tree
19	Myrtaceae	*E. ficifolia*	Red flowering gum	14.72	Ex	*Eucalyptus*
20	Amaryllidaceae	*Allium cepa*	Onion	14.31	Ex	Crop
21	Myrtaceae	*E. lehmanni*	Bushy yate	13.53	Ex	*Eucalyptus*
22	Vitaceae	*Vitis vinifera*	Grape	10.64	Ex	Crop

3.4. Discussion

3.4.1. Percentage Return of National Questionnaire

In the last three decades there have been four questionnaire based studies done on the beekeeping industry in South Africa. The most recent was performed by Conradie and Nortjé (2008) in which 500 hardcopy questionnaires were mailed to beekeepers registered to SABIO at the time, this study recorded a 22.4% response rate in which 112 completed questionnaires where returned. This survey covered an estimated 19 520 managed honeybee colonies. Allsopp and Cherry (2004) executed a questionnaire based survey aimed at establishing the value of *Eucalyptus* species to the beekeepers of the Western Cape in 2004. In this survey, hardcopy questionnaires were sent out to an address list of SABIO registered beekeepers, as well as unlisted beekeepers. This survey obtained a response rate of 19.05% (173 response from 908 beekeepers), and covered 33 836 managed honeybee colonies in the Western Cape alone. In 1995 van der Merwe and Elloff (1995) circulated a questionnaire to a select 250 beekeepers which received a 57% response rate (143 responses from 250 beekeepers). A national survey in 1975 achieved a 40.4% response rate (702 response from 1736 questionnaires released), and covered 60 389 managed honeybee colonies (Fletcher and Johannsmeier, 1978; Anderson, 1978). This 1975 national survey was focused on identifying general beekeeping information, such as managed honeybee colony numbers, honey and wax yields and pollination services rendered (Fletcher & Johannsmeier, 1978). This was the last national honeybee industry survey conducted on such a large scale until this study.

The questionnaire survey conducted for this study was distributed via various channels as well as posted freely available online on the SABIO website. Consequently, an exact number of questionnaires distributed is unknown, however over 1500 hardcopies were distributed. In total 219 responses were received back, covering 50 067 managed honeybee colonies. An exact count of the number of managed honeybee colonies in South Africa has not been accurately collected in recent time. However in Allsopp and Cherry (2004) study they postulated that there are approximately 120 000 managed honeybee colonies in South Africa. This estimation is based on data collected for their study of the Western Cape honeybee industry, and cannot be assumed to be an accurate representation of South African colony numbers. If however the response rate for this survey were to be based on Allsopp and Cherry (2004) estimation, this study response rate could represented approximately 41.72% of South African managed honeybee colonies. When this study was in the planning process the questionnaire was aimed at targeting 50 000 colonies, with an adequate return from each of the six provincial regions and thus the study achieved its response rate goal. The number of colonies was considered more important in this study than numbers of completed honeybee forage questionnaires per se, as national numbers of colonies and the types of forage that supports them was of primary interest. With a potential representation of 41.72% of managed honeybee colonies in South Africa, it is believed that the findings of this study give a true representation of the present managed honeybee national forage use.

That said, faults within this study lie in the distribution methods of the questionnaire to active beekeepers. As beekeepers are not required by law to be registered with a central governing association there are managed honeybee colonies belonging to beekeepers that are not registered and possibly did not receive the circulated information. As a result, this survey did not reach all South African beekeepers. Once the questionnaire had been circulated, a number of beekeepers approached us and questioned our motive behind the study. Overall, however, this study reached its goal of achieving a 50 000 managed colony response with reasonable proportional representation from each provincial region, and is thus seen as having obtained a fairly adequate representation of South African hive numbers and regional forage use.

3.4.2. Provincial Vegetation Type Usage

Regional/Provincial generic vegetation data was collected where beekeepers were unsure of the exact species their managed colonies were foraging upon. It was speculated that the vegetation type data was more a representation of the hobbyist beekeepers forage usage patterns, as they generally only keep a limited number of colonies on a hobbyist basis, and are often unsure of their colonies exact forage patterns. In contrast, we found that with responses from the larger commercial beekeepers, they had a good understanding of the forage species being used. Nonetheless, the questionnaire's vegetation data gave some important insights into forage usage. As expected, different vegetation types were used in different regions, except “suburban gardens” which was used significantly (≥10% of colonies use this source) in three provincial regions. The Free State, Gauteng, North West regions and the Western Cape region have an especially high usage of suburban gardens, but this can most likely be related to the fact that these regions include the large metropolitans of Johannesburg-Pretoria and Cape Town. Samnegård *et al.*, (2011) highlight the importance of private gardens as an important forage resource for honeybees, as they represent a source of large numbers of good quality foraging species and valuable nesting sites that are unavailable in commercial agricultural landscapes. In light of this evidence, there is potential for the growth/enhancement of South African forage in the suburban landscape.

The Western Cape, which was represented by highest numbers of colonies (Table 3.6), has a very diverse vegetation type usage whereby six vegetation types are used with high importance (Appendix II). The Fynbos Biome is well known for its remarkable floristic diversity, both for species and many different vegetation types (Mucina & Rutherford, 2006). The Northern Cape beekeepers have a strong reliance on the both the Nama and Succulent Karoo as a forage source, as approximately 90% of their honeybees spend time here.

3.4.3. Exotic vs. Indigenous Forage Species Usage

This study’s data and results are a qualitative description of the current South African forage use pattern, whereby the data describes the current use patterns. The results from this study suggest that there is a large diversity of honeybee forage species used across South Africa, of which there is a mixture of exotic and indigenous species. For example, the combined provincial grouping of the Free State, Gauteng and North West provinces along with the Western Cape have the highest used forage species diversity (Fig. 3.1). All six of the provincial regional areas have a different make-up of important forage species; however, there are certain forage usage patterns which can be identified across of the provinces. Patterns such as the broad usage of crop and *Eucalyptus* forage species throughout South Africa, and the overall dominance of exotic forage species (Fig. 3.1 & 3.2). It is, however, not simply the number of forage species in different categories that are important. This project was aimed at assessing the most important forage species used by beekeepers in different provincial regions and as such all forage species that have been used by more than 10% of the honeybee colonies in a region are regarded as important. Interestingly, the diversity of forage species is dramatically reduced when only species that are of importance are examined (on average only about half the numbers of species remained). This indicates that forage species differ markedly in their potential use for beekeepers and that there is strong selection for certain primary forage species in South Africa.

In general, there were no important shrub species used in any region of South Africa, and only one important tree species was used in the Northern Cape, *Prosopis spp*. which is used by 94.75% of Northern Cape colonies. Only two regions used exotic weed species heavily, namely the Free State/Gauteng/ North West region and the Western Cape, both regions using two exotic weed species. All six regions used both *Eucalyptus* and crop species extensively, with the Mpumalanga/Limpopo region using the highest number of important crop species (11 species). The Western Cape used the highest number of *Eucalyptus* species heavily, namely seven species, the most heavily used being *Eucalyptus cladocalyx* (78.98%). Indigenous shrub and tree species have been used more than exotic shrub and tree species. The Mpumalanga/Limpopo region used six indigenous tree species extensively, along with the Northern Cape beekeepers that used four species. Indigenous shrub species were important to beekeepers in all regions of South Africa, except for KwaZulu Natal. Throughout South Africa beekeepers used exotic species on a heavier basis than that of indigenous species, however, it could be argued that this is because of the contribution exotic *Eucalyptus* and crop species, for which there are no indigenous equivalents.

***Eucalyptus* as Honeybee Forage**

In terms of exotic forage species, the most significant and consistently used throughout South Africa are *Eucalyptus* species. *Eucalyptus* species are used by beekeepers in all six provincial region areas, and are used as an important forage sources in all regions. In recent years, *Eucalyptus* species have come under threat of removal in South Africa due to their water usage and invasive status. Particularly seven *Eucalyptus* species have been listed for control in the CARA (Act 43 of 1983), and work by the Working for Water program has already made an impact on these species (Allsopp & Cherry, 2004). *Eucalyptus grandis* (Saligna gum) is used considerably in five of the six regions this study covers (Fig. 3.1 & 3.2), and is only excluded from the Northern Cape. As *E. grandis* is listed on the CARA act for removal, immediate threat of honeybee forage declines are a real consideration. Furthermore in the Eastern Cape; KwaZulu Natal and Mpumalanga/Limpopo regions *E. grandis* is listed as the most important forage source (Tables: 3.1; 3.3 & 3.4), and its removal will be heavily felt by beekeepers. *E. grandis* is grown commercially in South Africa, and makes up 73.8% (approximately 441 394ha) of the total commercial forestry planted in South Africa (Snedden, 2001), it is however debatable as to the extend commercial forestry would be impacted by the CARA legislation as it is informal woodlots that are used heavily by beekeepers. A species that is also listed on the CARA list and is mentioned by Johannsmeier (2001) to be the most significant honeybee forage species in the Western Cape is *Eucalyptus cladocalyx* (Sugar gum). *E. cladocalyx* is an important forage source in two regions including the Eastern Cape (24.53%) and the Western Cape where 78.98% of all managed honeybee colonies forage upon it. Potential consequences of the removal of this forage species on the Western Cape beekeeping industry, as well as all related industries (deciduous fruit/seed industry) are vast. In KwaZulu Natal there are only four forage species that contribute forage to ≥10% of the 8448 colonies with which this study represents, one of these four is *Eucalyptus sideroxylon* (black ironbark) which provides forage for 47.35% of the colonies; however, *E. sideroxylon* is also listed on the CARA list. If this forage species, along with *E. saligna* is to be removed, it is unlikely that the remaining two agricultural crop species will be able to support the regional colonies. A similar situation exists in the Northern Cape where *E. sideroxylon* is used by almost 90% of 5562 managed honeybee colonies. In the Free State/Gaurteng/North West; Mpumalanga/Limpopo; Northern Cape as well as Western Cape *E. camaldulensis* (river red gum) is listed as a significant forage source. *E. camaldulensis* can form extensive and dense stands along watercourses, consequently is listed on CARA and is a primary target for removal by the Working-for-Water programme (Henderson, 2009). As this species does have the potential to disrupt watercourses and invade potentially sensitive ecosystems the need for removal is evident, however removing such a portion of the forage resource across a national scale will place additional pressure on other forage species to provide more forage in replacement. *E. paniculata* is listed as the most important forage source in the Free State/Gauteng/North West area providing forage for 56.60% of the 3597 colonies this study covers (Table 3.2). As this species is listed on the CARA list, it too is under threat of removal. Many of the *Eucalyptus* species that have been targeted for invasive alien plant clearing programmes in many parts of South Africa (Forsyth *et al.*, 2004), are also heavily relied upon as a forage source for South African beekeepers, this point however has not always been taken into consideration when alien invasive clearing programs have instated in an area.

Agricultural Crops

This study highlights the importance of a number of honeybee forage species, and after *Eucalyptus* species, it is clear to see that commercial agricultural crops play a significant role in maintaining South African managed honeybee colonies in all six provincial regional areas (Fig. 3.1 & 3.2). In the Free State/Gauteng/North West region there are a number (13 species) of agricultural crops used by beekeepers during the year, however only five of these play an important role. *Macadamia spp.* (Macadamias) and *Helianthus annuus* (Sunflowers) are both used by beekeepers extensively. In the KwaZulu Natal region alongside the two *Eucalyptus* species, it is the commercial crop *Citrus spp*. and *Helianthus annuus* which both support more that 80% of the 8448 colonies (Table 3.3), although there are shrubs and tree species that are used, their contribution is insignificant. The region which relies on Crops species the most heavily is Mpumalanga and Limpopo which use 15 crop species, of which 13 are used by more than ten percent of honeybee colonies.

Forage Use per Province

Interestingly in the Eastern Cape there are only two significant indigenous forage species, namely *Acacia karroo* and *Scutia myrtina*, and although there are only two important species there are 13 which were identified in this study (Table 3.1). The FreeState/Gauteng/NorthWest indigenous forage pattern indicates a stronger usage of indigenous species, out of a total of 18 indigenous species, eight are used by more than ten present of the colonies, the most popular being *Ziziphus mucrononata* (Buffalo thorn); *Acacia caffra* (Common hook thorn) and *Acacia mellifera* (Hook thorn), all three being common tree species in this region.

Mpumalanga and Limpopo beekeepers used a total of 15 agricultural crops, of which 11 support ≥10% of the colonies. The highest listed being *Persea americana* (Avacado) 63.76%, followed by *Macadamia*; *Litchi* and *Citrus* species (Table 3.5). Johannsmeier (2001) states *Citrus* to be a major forage source in the Mpumalanga province, in another article by the same author (Johannsmeier, 1998) *Persea americana* are identified as an important forage resource, a trend identified in the questionnaire. This diversity of agricultural crop species seems to point towards a more diverse agricultural landscape, where forage is available across a wider scale. At the same time there are a number of indigenous tree (11 species) and shrub (three species) species (Fig. 3.2) that contribute prominently. The value of this diverse range of forage species seems to indicate that the forage outlook is possibly fairly stable in this area. In terms of enhancing forage resource in Mpumalanga and Limpopo with indigenous species, there are a number that stand out, namely: *Aloe marlothii*; *Acacia karroo*; *Aloe greatheadii subsp davyana* and *Searsia lancea* all of which provide substantial forage resources (Table 3. 4). Aloe species are used as one of the strongest indigenous honeybee forage sources, especially over the winter months in South Africa (Human & Nicolson, 2008).

The Northern Cape forage usage describes a pattern more orientated towards indigenous forage species. *Acacia mellifera* (98.74%) and *Acacia karroo* (98.63%) are the highest listed forage species, covering basically all the managed honeybee colonies in the region (Table 3.5). The overall percentage of all the forage species is very high in the Northern Cape due to the response of a single beekeeper with 5000 managed colonies. Subsequently all the forage species that this particular beekeeper used has a very high percentage as the total managed honeybee colonies documented in the Northern Cape was 5562 (Table 3.5).

The Western Cape is the best represented province in this study, with 23 157 manage honeybee colonies (Fig. 3.2), a proposed reasoning behind this positive response is speculative. It is possible that due to the Western Cape's beekeepers seemingly respectable relationship to SABIO and the ARC it may have helped in assuring beekeepers that their responses would be treated with discretion. Allsopp & Cherry's (2004) survey of Western Cape beekeeping and the value of *Eucalyptus* most likely helped, as with their survey the Western Cape beekeepers were able to witness the positive results of a research survey and as such were willing to participate in this study. Beekeepers in the Western Cape are fortunate in the diversity of indigenous forage species available to them, however, forage usage is dominated by exotic species (Fig. 3.2). Allsopp and Cherry's (2004) survey results show that 87% (29 438 colonies) of Western Cape managed honeybee colonies are used for pollination and 74% of the colonies spend approximately 75% of the year on CARA-listed *Eucalyptus* species.

The results of this study indicate a similar pattern of high importance of *Eucalyptus* usage with six *Eucalyptus* species listed as being important in the Western Cape alone (Table 3.6). In total there are 17 species of agricultural crops used and 13 species of *Eucalyptus* (Fig. 3.2). Of these *Eucalyptus* species, seven are used considerably, of which four are listed on the CARA list as invasive and water users. Whether this quantity and quality of *Eucalyptus* forage can be replaced is an unknown question, and certainly from Allsopp and Cherry's (2004) survey they noted that without replacement of removed *Eucalyptus* species, managed beekeeping would not survive.

Agricultural crops used by beekeepers in the Western Cape are also diverse, with *Brassica napus var. oleifera* (Canola) being the highest listed species (Table 3.6). This species is used by beekeepers extensively for harvesting wild swarms in the spring time, as well as a source of pollen and nectar (Langenhoven, 1999). As expected in this region, the deciduous fruit industry plays an important role for managed beekeeping, as beekeepers earn an income from pollination service rendered to deciduous fruit farmers. There are an additional four exotic weed species that are important to beekeepers in this region. *Echium plantagineum* (echium) and *Raphanus raphanistrum* (wild radish) are both used extensively on fallow agricultural land or on marginal land in the agricultural landscape. *Raphanus raphanistrum* is well known to be heavily visited by an array of generalist insects pollinators, as it produces a strong forage supply (Ghazoul, 2006). In terms of indigenous species, there are only five tree and shrub species that provide a significant forage resource. *Mesembryanthemum spp.* (Aizoaceae); *Erica spp*.; *Protea spp*. and *Agathosma spp.* of the fynbos vegetation type are the main sources of forage for honeybees in fynbos apiaries. *Mesembryanthemum* species are a well-used nectar and pollen source in the winter months

(Johannsmeier, 2009). Indigenous forage species of the Western Cape are used primarily in the winter time and as a honey crop. Beekeepers whose business is pollination services use *Eucalyptus* and agricultural crops such as *Brassica napus var. oleifera* as they require these strong flows to ensure their colonies are up to strength before they go into agricultural crops for the pollination season.

To conclude, beekeepers have particular forage species use patterns that differ between regions, although weighted primarily to *Eucalyptus* (most regions) and flowering crops (half of regions). This strong pattern shows that it is not simply the number of good pollen and nectar species that occur in an area that determine forage use but also their abundance. Under natural conditions indigenous species would be scattered and rarely form large single species dominated stands. In contrast, *Eucalyptus* stands and especially planted crops can form large single species stands. Therefore, if beekeepers are expected to make use of only indigenous species, these would have to be planted or managed to form the same high species density. This is however not feasible due to the potential environmental impact that would result and the astronomical cost of planting these species with the sole use as bee forage. Certain indigenous tree species are also listed as bush encroacher species and additional plantings of these species could cause problems.

3.4.4. Managing South Africa's Honeybee Forage

The heavily weighted exotic species usage pattern by South African beekeepers places perspective on the potential dangers of legislation such as CARA in terms of the knock on effects on the beekeeping and related industries. Although it is clear that invasive species need to be removed and/or controlled where there are potential negative ecosystem impacts occurring, the removal of such species is bound to have a substantial impact on the honeybee industry. With the removal of invasive species, a program could be introduced whereby forage resources that are removed are replaced. However, whether indigenous honeybee forage species have the ability to fill this gap is an argued point. This study shows that although beekeepers are using indigenous forage species across South Africa, their usage is outweighed by the contribution of *Eucalyptus* and agricultural crop species. Johannsmeier (2001) stated that given South Africa's limited forage resources, the beekeeping industry would not have reached the point where it is today without the contribution of *Eucalyptus* species.

Although the original mandate which was set out was orientated towards the identification of indigenous honeybee forage species that could be used to replace exotic forage species, it became clear that the potential of finding such an indigenous species in each region was unlikely. In all regions a dominant *Eucalyptus* species maintains between half and nearly all hives kept in a particular region. No provincial region of South Africa has an indigenous forage source that matches the most frequently used *Eucalyptus* forage species, apart from the Northern Cape where *Acacia mellifera* and *Acacia karroo* are equivalent in percentage use.

A realistic approach to future steps in honeybee forage protection is through the enhancement of non-invasive honeybee forage resource before the clearing of invasive forage, more so than the outright replacement of exotic forage species. For instance where CARA-listed *Eucalyptus* species exist in watercourses or are disrupting natural habitats these should be removed, but at the same time areas which are not susceptible to invasion or are not already planted with honeybee forage should be investigated as possible areas for honeybee forage enrichment. A good example of a planting project that was undertaken to plant trees to fulfill multiple roles including the provision of honeybee forage is a project under way in Israel (Keasar & Shmida, 2008). This planting project identifies tree species that are able to answer a combination of needs such as defence against erosion, improvement of environmental quality, wood supply, upgrade outdoor leisure sites and at the same time provide honeybees with a solid forage source. Beekeeper planting of forage plants for the sole purpose of forage resource supply are often unrealistic and unprofitable (Paul Ransom pers. comm., 2011). The answer to this problem is the planting of plant species that have multiple roles/uses such as the Israeli project has undertaken to do. Such a project has been started in the Western Cape whereby a commercial beekeeper has planted *Eucalyptus* trees on a privately owned land space and is growing *Eucalyptus* with the goal of harvesting the timber once the trees have reached the appropriate size (Ransom, 2008), and in the meantime using the *Eucalyptus* as a forage source. By managing and demarcating these *Eucalyptus* stands, the invasive potential of these species can be limited so that a “win-win” scenario is created with the benefits of forage provision outweighing the negative aspects of water use and invasion.

3.5. Conclusion

Questionnaire centered studies based on the South African beekeeping industry have been performed on a number of occasions, yet none of these previous studies specifically focused on the South African honeybee forage use scenario. This study thus provides the first forage species use list for South Africa, divided into six regions. Although this study’s response rate was viewed as high and the number of colonies represented significant (with only Fletcher and Johannsmeier (1975) representing more honeybee colonies nationally), uneven response distribution between regions indicate that forage importance differs regionally and consequently findings must be accepted on a regional basis. Additionally, specific species contributing to regional forage use differs, which is important to take into consideration when coming up with forage management strategies. Region specific forage management strategies will ensure effective action can be taken to develop forage resources based on each regions requirement. Beekeepers forage species use patterns are likely to change differently per region, as pressure for the removal of certain exotic forage species, and the use of agricultural pesticides on crops, differs per region. The beekeeping industry will be forced to adapt to these changes, but holistic and efficient forage resources management will be critical to allow such adaptions.

The main forage resources used currently by beekeepers throughout South Africa are an assortment of exotic species, mainly consisting of *Eucalyptus* and agricultural crop species. Indigenous species are used by beekeepers in all regions of the country, however mostly on a minor scale only. There are exceptions, where by some regions use indigenous species on an equal basis to exotic species. Overall however, exotic species remain the dominantly used forage resource in South Africa. The removal of listed *Eucalyptus* species would thus impact all provincial regions studied. The next piece of information required to evaluate the importance of frequently used forage species are these individual species' relative weighted contributions to supporting managed hives. Only then can the contribution of listed species be fully quantified, and the implications of future removal be fully understood. Nonetheless, the current patterns of forage species use illustrated indicates that a simple replacement of exotic species with indigenous is simplistic, practically unrealistic, and would have major implications for managed beekeeping and crop pollination in South Africa.

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Chapter Four

GENERAL DISCUSSION AND CONCLUSION

4.1. Rationale for the Study: Past and Current Honeybee Forage Usage Patterns in South Africa

This study was prompted by the discontent which developed between the South African beekeeping industry and the Working for Water Program (WfW) as a result of the latter's intention to control targeted *Eucalyptus* species in the South African landscape, and the beekeepers resistance to such control measures due to the value several *Eucalyptus* species hold as honeybee forage (Nicolson, 2011; de Lange *et al.*, 2013).

The *Eucalyptus* species, regarded as a highly important forage sources by the South African beekeeping industry are listed as environmentally destructive (invasive water users) in the Conservation of Agricultural Resources Act 43, 1983 (CARA List) (Glazewski, 2005), and are marked up for control (Allsopp *et al.*, 2008). In total, seven *Eucalyptus* species are listed on the CARA, with *Eucalyptus lehmanni* (Spider gum) categorized as "most destructive" warranting unconditional removal. The remaining six may be retained in non-sensitive ecosystems under permit (Allsopp & Cherry, 2004). All of the seven listed *Eucalyptus* species are reported to play an important role in providing honeybee forage throughout the year, and the loss of these species could potentially have serious implications for the beekeeping industry. Consequently, conflict arose between the beekeeping industry and environmental agencies responsible for the control and eradication policy, creating the necessity for further research into the issue of the importance of *Eucalyptus* for the South African beekeeping industry and the forage resources that the industry relies on.

The importance of the pollination services provided by honeybees is widely documented in international (e.g. Klein *et al.*, 2007) and South African (e.g. Allsopp *et al.*, 2008) literature. Commercial honeybees are used to pollinate at least 26 crops in the Western Cape alone, particularly in the deciduous fruit industry (Allsopp & Cherry, 2004). Additionally throughout South Africa, agricultural industries are equally reliant on managed honeybee pollination, one such example is the seed industry.

This study focused upon identifying the past and current honeybee forage usage patterns in South Africa thereby identifying significant forage species, both exotic and indigenous. The first step was to determine what historically has been the most significantly used honeybee forage species in South Africa, through a honeybee forage literature review spanning the last 90 years. Secondly, the current honeybee forage usage pattern in South Africa was identified through a national honeybee forage questionnaire survey.

4.2. Honeybee Forage Usage Patterns over the Past Ninety Years: Historical Review

Past honeybee forage usage patterns identified through my literature review revealed that forage patterns, although having slightly shifted towards a more indigenous forage species usage, have remained predominately exotic throughout the last 90 years. Each provincial region displayed a differing usage pattern whereby differing regional areas used different assortments of exotic and indigenous forage species. Overall, exotic forage species were responsible for providing 68% of all honeybee forage across South Africa, the remaining 32% being indigenous species. In the latter years of the review, however, increased indigenous forage species use indicated a shift of forage usage patterns away from exotic species. This notable change from the earlier years of the review, where exotic species made up almost three quarters (73% of total forage used) of the forage use, to the latter years of the review where exotic species use decreased to less than two thirds (63% of total forage used) indicated a general shift across all provinces to increased indigenous forage use. Of the exotic species used, the most heavily cited species were that of 27 *Eucalyptus* species, which according to the literature 31% of all South African forage literature references are *Eucalyptus*.

4.3. Current Honeybee Forage Usage Patterns

Honeybee forage species currently being used by beekeepers in South Africa was obtained via questionnaire data which revealed a similar trend exists currently to that of historic forage use patterns. Questionnaire data showed that currently a large range of honeybee forage species are used across South Africa, consisting of a mixture of both exotic and indigenous species. Despite each provincial region having a different forage species makeup, one common pattern was observed across all regions; namely, the general; use of *Eucalyptus* and agricultural crop species across all provincial regions highlighting the importance of exotic forage species in South Africa. Questionnaire data also revealed provincial differences in forage use, except in the case of “suburban gardens” which beekeepers ubiquitously used across South Africa. Urban environments offered a diversity of high nectar and pollen quality flowering species for honeybees, and should be investigated in terms of the potential for urban municipal forage planting schemes. Similar schemes have been highlighted in other parts of the world, whereby urban environments are promoted as honeybee friendly environments (Samnegård *et al.*, 2011). Where agricultural and forestry industries are often monocultures or negatively affected by poisonous by-products harmful to honeybees, urban environment's forage potential could be enhanced. In South Africa however, due to the defensive nature of indigenous honeybee species almost all municipalities have rules preventing urban beekeeping. With such a diversity of forage in South African urban environments, the integration of beekeeping into urban landscapes through safe measures is a concept which could be explored to strengthen forage availability.

4.4. Changes in Honeybee Forage Usage Patterns

This study has shown that past and current honeybee forage usage patterns follow a fairly similar trend, with beekeepers using a diversity of forage species, both exotic and indigenous. In both instances, exotic species have been the predominant forage species used. The only notable change in forage usage patterns was an increased awareness from beekeepers towards the use of indigenous forage species. Although the use of indigenous species did not outweigh the dominance of exotic forage, the degree that beekeepers valued indigenous species increased, especially in the last 20 years. In this thesis I speculate that a possible cause of this increased awareness and use of indigenous forage species stems from the amplified pressure being placed on invasive species removal.

In the Western Cape very little change in terms of forage usage was observed over the 90 year review period as this province consistently used the highest number of *Eucalyptus* species, the most significantly being *Eucalyptus cladocalyx*. Approximately 80% of all Western Cape colonies are recorded to forage upon this one species alone, consistent with Johannsmeier's statement (Johannsmeier, 2007) that *Eucalyptus cladocalyx* is the most important honeybee forage species in South Africa. In a recent paper, de Lange *et al.* (2013) argue that the value of *Eucalyptus cladocalyx* outweighs the cost of its water use, if having to replace this species as a forage source, which adds emphasis to the importance of the contribution this species makes to honeybee forage security. The true value of *Eucalyptus cladocalyx* in practice lies in its summer flowering (December to February) pattern, providing excellent forage when little or no alternative forage is available. It thus fulfils a niche role in the annual cycle of forage provision (de Lange *et al.*, 2013). Additionally, *Eucalyptus* species, *Eucalyptus grandis* (Saligna gum) was also still used considerably in five of the six regions this study covered, only being excluded from the Northern Cape. Although both *E. cladocalyx* and *E. grandis* are listed on the CARA act as "invasive species" they are not officially declared invaders; therefore, although the threat of honeybee forage declines are a real danger, with correct management such negative impacts could be avoided.

Agricultural crop species were observed to play the second largest role as important forage species throughout South Africa. The extensive use of this forage category was consistently high across all provinces. Interestingly, there were a few species that stood out from amongst the diversity of crop species used by beekeepers. For example, two species used in all regions of South Africa were *Helianthus annuus* and *Citrus spp*., being used both in the past and currently still considered important forage sources. The recent, and extensive use of *Brassica napus var. oleifera* (Canola) was noted for the Western Cape. This particular species was not available in the past, but has become important in recent years (Langenhoven, 1999) with its increased hectarage planted.

Changes in indigenous forage species usage has been observed fairly extensively across South Africa, baring KwaZulu Natal, where an increased use of indigenous species has not occurred. Indigenous species were broadly used in some areas, such as in the Mpumalanga/Limpopo region and in the Northern Cape where indigenous tree species are heavily relied upon by beekeepers. *Aloe greatheadii var. davyana* (davyana aloe) was observed to be especially heavily used both historically and currently and appears to be an important resource. This species provides important over-winter forage in the northern regions of South Africa and is considered one of the most important honeybee plants in South Africa (Fletcher & Johannsmeier, 1978; Johannsmeier & Mostert, 2001; Human & Nicolson, 2006; Human & Nicolson, 2008). In recent years an increasing number of species are considered important, such as *Mesembryanthemum spp*. (Aizoaceae), *Erica spp*., *Protea spp*. and *Agathosma spp*. (Hepburn & Guillarmod, 1991). *Mesembryanthemum* species are a well-used nectar and pollen source in the Western Cape in the winter months (Johannsmeier, 2009). This study found that although indigenous species play a role in providing minor forage sources to bridge the gap between major nectar and pollen flows, it is the exotic species that provide the significant honeybee forage resource and this factor has not changed.

4.5. Future Considerations

The South African pollinator resource (both managed and wild) requires protection from human- and environmental-induced threats that could jeopardise this critical service. With a number of threats facing these pollinators (Oldroyd, 2007; Pirk *et al*., 2014), especially the honeybee, one of the key risks requiring management is that of the supply of adequate forage. Forage resources for managed honeybees need to be adequately provided in order to maintain the colonies when agricultural crops are not in flower, so that when managed colonies are required for pollination they are healthy and strong.

From this study a clear pattern of past managed honeybee forage usage has been identified, and the important forage species, both exotic and indigenous have been recorded across South Africa. The interaction between South African beekeepers and the forage resource should not be taken lightly, but be taken forward and recognised as an essential component in South African food security. The removal of the exotic component of this forage resource could lead to a break in the annual managed honeybee forage use, leading to a possible decline in our ability to pollinate all necessary agricultural crops. Aizen *et al.*, (2009) report that the global agricultural demand for managed pollination service is growing faster than the supply of domesticated honeybees as honeybee populations are under threat from various factors. Although this may be true for America, and parts of Europe, it is as yet not such serious reality in South Africa (Neumann & Carreck, 2010; Strauss *et al.*, 2013). That said, Pirk *et al.*, (2014) have recently reported that South African honeybee colonies are beginning to show signs of decline and weakness. Thus global issues should be taken into account if pollination services provided by honeybee colonies are to be conserved; the potential for a serious decline in South African honeybee pollinators is a real threat if action is not taken to ensure the ultimate survival and growth of honeybee populations. The findings of this study could be seen as an opportunity for further research into the development of forage resources, with regards to developing a diverse and sustainable honeybee forage resource across South Africa. As without the diversity of honeybee forage species, both minor and major the South African beekeeping industry would not be able to sustain the honeybee colonies needed for agricultural pollination.

Honeybee forage development policies should not only benefit managed honeybee colonies but that of wild honeybee populations (as well as all other insect pollinator species) as the protection of indigenous natural swarms is essential for the South African honeybee industry, since the majority of South African beekeepers rejuvenate their honeybee colonies via wild swarm capture (Johannsmeier, 2001).

To guarantee the future protection of honeybees a number of steps should be taken to achieve a sustainable and healthy forage environment. Apart from dealing with threats associated with various pests and diseases, honeybee forage resources need to be taken into account and the implications of forage loss needs to be accurately calculated. Firstly, the current managed and wild honeybee pollinator forage requirement needs to be determined as a whole, and what the future demand will be. Whether or not the current forage resource is sufficient to allow for the growth of honeybee pollinator populations will determine how necessary the expansion and development of forage resources are. Secondly, an appeal for pollinator forage protection needs to be made, as in order to develop the forage resource it is essential to maintain what already exists. Thirdly, all factors relating to honeybee pollinators, both biophysical (habitat and forage resources) and the economic implication of the loss of pollinator service resulting from a loss of forage needs to be assessed. For the time being conservation of agricultural pollinators should be of utmost priority, and the removal of the critical exotic forage resource that maintains these pollinators needs to be urgently reassessed incorporating the entire cost of such removal.

4.6. Conservation and Management Recommendations

To effectively characterise and identify significant and well used honeybee forage sources in South Africa, both the past foraging patterns along with current foraging patterns had to be researched. These methods can give one an understanding as to how particular forage resources are more extensively used over other minor resources, not only currently but the extent to which they have been used in previous years. The results of this study adds emphasis on the need to consider the implication of forage loss, and the value of these species. Monetary valuation is important when decision-makers are faced with a limited budget and conflicting goals, as can be the case in the conservation of ecosystems services (Farber *et al.*, 2002). However, it is essential not to forget the interconnectedness of the differing forage sources and how they are used in a pattern throughout the year, and not focus upon a few species, but instead of the system as a whole when considering conservation and management practises. An action to protect or enhance one component of the forage resource system will inevitably affect the system as a whole. As a result it is necessary to approach the protection and management of honeybee forage resources at a local, national/landscape and governmental scale.

4.6.1. Beekeeper Scale

Beekeepers provide essential pollination services to commercial agricultural crops in South Africa. This pollination service provided by managed honeybees is made possible through the forage resources beekeepers use on a day to day basis, allowing them to harvest wild swarms and/or to strengthen colonies that are ultimately to be used to pollinate agricultural crops. It is thus essential for beekeepers to have access to a diversity of honeybee forage sources throughout the year, to be able to ensure effective pollination colonies when agricultural crops come into bloom. Beekeepers need to take responsibility for the forage resources they use in order to maintain them. This could be achieved from simply conversing with landowners as to the importance of the forage found on their land which colonies forage upon, to integrating themselves into the policy making process regarding the forage resource. Very few, if any, beekeepers in South Africa own the forage resource they use as the cost involved in owning such extensive land is too high. As such, beekeepers rely on agreements with landowners (be it state land; farmers; private land owners) to forage their managed colonies on particular forage resources. Beekeepers thus should be encouraged to advise the landowners, with clear reasoning, as to the importance of conserving the forage resource on the land, not only for the beekeepers economic benefit but also for the conservation of agricultural services provided by honeybees. Honeybee forage development or the enhancement of existing forage resources should be encouraged amongst beekeepers, as ultimately it is their industry they are tasked to protect. For example, beekeepers should encourage landowners to leave natural vegetation surrounding or adjacent to agricultural land unscathed, and not be further developed into farmland in order to provide foraging opportunities for managed and wild honeybees. Further planting of flowering resources could aid in enhancing already existing forage resources in natural vegetation. It is the responsibility of beekeepers, as much as government policy-makers, to ensure the continued secure supply of honeybee forage resources. It is the responsibility of beekeepers to take an active role in promoting healthy environments, free of pesticides and other potential threats to their managed colonies, as well as provide safe and secure honeybee forage resources.

4.6.2. Provincial and National Scale

The responsible party for the protection and development of honeybee forage resources across provincial and national scales is difficult to isolate, as it stretches across several landowners and industries. The ideal method of honeybee forage protection and development would be through a collaborative project between local government such as DAFF (Department of Agriculture, Forestry and Fisheries), regional beekeeper associations (e.g. Western Cape Beekeeping Association), industry bodies (South African Bee Organization) and associated agricultural bodies (Deciduous Fruit Growers Trust). On the provincial scale protection of forage resources needs to incorporate the main forage resource areas, which can only be achieved once these areas are locally identified by beekeepers themselves. This study has very broadly highlighted the most important forage sources according to South African beekeepers and their historic usage patterns; however, the exact location, quality and quantity of these resources needs to be further identified. Conflict has arisen between beekeepers and environmental agencies, with regards to the removal of key forage species. Landscape management, protection and the development of forage resources needs to come in the form of large scale awareness projects that not only promote the protection of existing forage resources but promote the development of forage species. Corridors of natural vegetation, consisting of flowering forage species connecting agricultural land to natural land could increase both the presence of honeybees in agricultural crops as well as increase honeybee forage. “Win-Win” species - forage species that have a primary function, for example forestry, with related secondary benefits, such as provision of honeybee forage, could also be promoted.

4.6.3. Industry Scale

Protecting and developing honeybee forage resources from an industry level should be approached from the viewpoint that industries are often only influenced from monetary gain. As such the monetary valuation of honeybee forage, and the cost involved in the loss of forage, not only to the beekeeping industry but related industries (loss of pollination service to deciduous fruit industry) could be used as leverage to promote the need for conservation from all industries. As such it is not only the honeybee industry (South African Bee Organization) but a diverse array of industries that rely on honeybee services for continued survival. All of these industries should take responsibility for the maintenance of the honeybee forage resource. There is currently global pressure to protect honeybee colonies, and the need to conserve forage resources falls into this movement. Global industry movements often affect local industries, and in the case of the South African beekeeping industry it should take note of the global trend to protect beekeeping as a whole and look towards their own forage resources. The pollination service beekeepers are providing to fruit producers (Allsopp *et al.*, 2008), and other agricultural industries is undervalued.

Other industry initiatives could be to develop a best practice guideline for the beekeeping industry and all related industries that can include farm-scale and landscape scale methods to protect existing forage species, and develop forage resources in areas which lack quality forage. Although this initiative would be addressed on beekeeper and landscape scale it would require the industry to drive it. The necessity for honeybee pollination services are only going to grow with the ever increasing demand for fresh produce, thus the demand for strong quality honeybee forage sources will remain strong.

4.7. Future Research

This study reveals the broad diversity of forage species as well as the annual foraging patterns managed honeybees have in the past and are currently foraging upon. However, individual forage species qualities, in terms of their ability to yield quality nectar and/or pollen resources, need to be investigated. In order to secure future honeybee forage resources, individual species need to be championed, species that do not pose a threat as an invasive species, and yet would act as a strong forage resource. Some of the research questions that could be addressed are: What method of honeybee forage enhancement would actively contribute the most to the honeybee industry? How are South African honeybee foraging patterns going to change in the face of changing agricultural systems?

Some of the conservation recommendations need to be addressed from a practicable implementation and management point of view. Further research should be taken forward with the intention of beginning implementation of honeybee forage enhancement projects. Relevant research questions could be: What conservation actions will best enhance honeybee forage resources? What conservation actions will actively contribute towards the protection of honeybee forage resources? This study focuses on the broad foraging patterns of South African managed honeybees; individual forage species highlighted in this study need to be assessed in a similar manner in order to add value and therefore reasoning for protection.

4.8. References

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Appendix I

Honeybee Forage Species Literature Review; *South African Bee Journal* Articles

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Time Frame 1 (1920-1949)

Author Name	Volume	Page	# Citation	Year
Aerial	V 15 - 18	7	2	1943
Andrews, C. A. M.	V 12-14	8	4	1937
Andrews, C. A. M.	V 12-14	12	2	1938
Andrews, C. A. M.	V 4 -7	16	1	1931
Anonymous	V 1	16	18	1922
Anonymous	V 1	26	17	1922
Anonymous	V 1	46	1	1922
Anonymous	V 1	36 - 37	17	1922
Anonymous	V 1	40 - 41	1	1922
Anonymous	V 1	5, 6	25	1922
Anonymous	V 1 -3	142 - 143	1	1921
Anonymous	V 1 -3	82 - 83	1	1921
Anonymous	V 1 -3		2	1921
Anonymous	V 12-14	6	1	1930
Anonymous	V 12-14	7	4	1937
Anonymous	V 12-14	9, 13	17	1938
Anonymous	V 1-3	92-93	4	1921
Anonymous	V 13(6)	4, 6	1	1939
Anonymous	V 19	2	1	1944
Anonymous	V 2	25	1	1922
Anonymous	V 2	84	1	1922
Anonymous	V 2	33 - 34	15	1922
Anonymous	V 2	66 - 68	4	1922
Anonymous	V 4 -7	4	7	1929
Anonymous	V 4 -7	16	6	1932
Anonymous	V 4 -7	20	1	1931
Anonymous	V 8 -11	3	1	1934
Anonymous	V 8 -11	8	1	1933
Anonymous	V 8 -11	12	9	1936
Botanical District Notes	V 1-3	128 - 129	3	1921
Botanical section	V 1-3	29 - 30	3	1921
Botanical section	V 1-3	43 - 45	6	1921
Cameron, J. R.	V 4 -7	21	8	1931

Author Name	Volume	Page	# Citation	Year
Cooper, F. H.	V 12-14	6	1	1937
Cooper, F. H.	V 8 -11	6	2	1936
Cooper, F. H.	V 8 -11	11	4	1936
Field, A. N.	V 4 -7	5	6	1932
Fusslein, E. R.	V 23	15 - 16	6	1949
Fyfe, G.	V 6(2)	15	2	1931
Gough, L. H.	V 4 -7		4	1928
Gray, L.	V 22	5	2	1942
Hannabus, C. H.	V 19		1	1945
Hardwick, L.	V 21	13	1	1946
Hayter, C. S.	V 12-14	12	3	1938
Hayter, C. S.	V 15 - 18	7	5	1941
Hayter, C. S.	V 4 -7	10	1	1931
Hayter, C. S.	V 4 -7	23	1	1931
Krohn, E. W.	V 4 -7	11	2	1931
Lang, N. L.	V 5(5)	19	1	1931
Liebenberg, L. C.	V 26	22 - 23	82	1949
Loock, E.	V 23	3, 5	14	1949
Loock, E.	V 26	23 - 24	121	1949
Marsh, E. K.	V 22	15	16	1947
Mogg, A. O. D.	V 20	8, 10	30	1945
Moore, A.V.	V 4 -7	11	3	1932
Pretoria BKA	V 19	5, 6	51	1944
Robinson, E. B.	V 15 - 18	8	1	1940
Root, E. R.	V 4 -7	11	2	1932
Savory, W.	V 8 -11	9, 10	9	1934
Taylor, F.	V 12-14	3, 5	20	1937
Thudichum, F	V 15 - 18	4	8	1942
van der Merve, J. D.	V 15 - 18	4	1	1941
Western Province BKA	V 21	15	2	1946
White, G. H.	V 19	7	6	1944
Wise, T. E.	V 12-14	9	2	1936

Time Frame 2 (1950-1979)

Author Name	Volume	Page	# Citation	Year
Anderson, R. H.	V 36 - 37	10	5	1965
Andrag, H. R.	V 48	6	10	1974
Anonymous	V 32	7	4	1957
Anonymous	V 38 - 39	9	1	1966
Anonymous	V 48	2	6	1976
Anonymous	V 49 - 50	10	3	1977
Anonymous	V 51	19	2	1979

Author Name	Volume	Page	# Citation	Year
Beuhne, F. R.	V 36 - 37	15	5	1965
Beyleveld, G. P.	V 39	10	6	1967
Beyleveld, G. P.	V 40	11	13	1968
Beyleveld, G. P.	V 40 - 41	13 - 14	42	1968
Botha, H. B.	V 33	3	8	1960
Bredenkamp, G. L.	V 44 - 45	12	4	1972
Crisp, W. F.	V 32	3	3	1957
Crisp, W. F.	V 32	12	10	1957
Davidson, V. R.	V 42 - 47		43	1970
Dull, K. M.	V 48	18	1	1976
Falconer, D.	V 48	4	1	1974
Ferreira, F. H.	V 27	6	15	1952
Findlay, M. S.	V 28(1)	19	1	1953
Goodwin, N.	V 38 - 39	14	1	1967
Guy, R. D.	V 44 - 45	9	1	1972
Guy, R. D.	V 42 - 47		2	1970
Guy, R. D.	V 44 - 45	5	3	1972
Guy, R. D.	V 44 - 45	11	2	1972
Guy, R. D.	V 47		9	1975
Johannsmeier, M. F.	V 42 - 47		1	1970
Johannsmeier, M. F.	V 44 - 45	2	1	1972
Johannsmeier, M. F.	V 48	10	1	1976
Johannsmeier, M. F.	V 49 - 50	9	1	1977
Kearsley, J.	V 26 - 27		2	1952
Kilian, P. G.	V 32	7	1	1957
King, L. K.	V 48	4	1	1972
Leith, F. N.	V 30 - 31	9	1	1955
Loock, E.	V 34 - 35	19 - 21	14	1963
Mindenhall, J.	V 44 - 45	2	9	1972
Mountain, P. N.	V 51	22	1	1979
Mountain, P. N.	V 50	3	2	1978
Myburgh, A. J.	V 44 - 45	6	1	1972
Ormsby, M.	V 34 - 35	11	8	1963
Reynolds, G. W.	V 34 - 35	2	1	1962
Schnetler, A. E.	V 42 - 47		1	1970
Short, F.	V 34 - 35	1	1	1962
Thudicum, J.	V 38 - 39	5	8	1967
Todd, I.	V 48	2	1	1974
Uys, N.	V 51	22	1	1979

Time Frame 3 (1980 – 2009)

Author Name	Volume	Page	# Citation	Year
Allsopp, M.	V 65(2)	32 - 36	1	1993

Author Name	Volume	Page	# Citation	Year
Booysen, J.	V80	107	1	2008
Botes, A. J.	V56 (2)	64 - 69	8	1984
Botha, J. J.	V 54(1)	11	8	1982
Botha, R.	V77	22	1	2005
Challen, M.	V 64(6)	125 - 126	1	1992
Clark, P. L.	V64(1)	3	1	1992
du Toit, A. P.	V 66(1)	9	3	1994
du Toit, A. P.	V 63(1)	21 - 22	1	1991
du Toit, A. P.	V75	24 - 27	1	2003
du Toit, A. P.	V78	2	1	2006
Editor	V 58	16	2	1986
Eksteen, J. K.	V 63(6)	128	18	1991
Gardner, R. A. W.	V76	44 - 47	40	2004
Hepburn, E. J.	V 54(1)	3	13	1982
Hepburn, H. R.	V 87	70 - 73	2	1991
Herrmann, J. M.	V 55(2)	26 - 33	1	1983
Howie, A.	V72	90 - 93	5	2000
Human, H. & Nicolson, S.	V79	25 - 27	1	2007
Illgner & Ploen	V 69(1)	7	2	1997
Illgner, P. M.	V68 (2)	52 - 53	3	1996
James, C. F.	V 67(5)	140	1	1995
Johannsmeier & Allsopp	V 67(3)	70	193	1995
Johannsmeier, M. F.	V79	35 - 42	202	2007
Johannsmeier, M. F.	V79	59 - 63	70	2007
Johannsmeier, M. F.	V73	31 - 35	32	2001
Johannsmeier, M. F.	V 53	7	31	1981
Johannsmeier, M. F.	V72	133 - 137	18	2000
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Appendix II

Provincial Vegetation Type, Honeybee Colony Usage

Provincial Region	Vegetation Type	% Colony use
Eastern Cape		
	Eastern Cape thicket	27.28
	Indigenous forests	6.70
	Mountain fynbos	5.13
	Suburban gardens	4.16
	Coastal fynbos	3.23
	Karoo	2.77
	Bushveld	0.65
FreeState/Gauteng/NorthWest		
	Bushveld	35.03
	Suburban gardens	22.94
	Karoo	3.89
KwaZulu Natal		
	Indigenous forests	3.67
	Suburban gardens	1.05
	Eastern Cape thicket	0.06
Mpumalanga/Limpopo		
	Indigenous forests	24.15
	Suburban gardens	21.63
	Bushveld	21.33
Northern Cape		
	Karoo	89.90
	Namaqualand & Renosterveld	1.26
	Suburban gardens	0.11
Western Cape		
	Mountain fynbos	35.04
	Strandveld	28.98
	Coastal fynbos	27.92
	Suburban gardens	17.15
	Karoo	12.42
	Namaqualand & Renosterveld	5.00
	Indigenous forests	4.01
	Bushveld	0.52